RELIABILITY EVALUATION OF SECONDARY DISTRIBUTION SYSTEM IN NIGERIA: A CASE STUDY OF AYETORO 1 SUBSTATION, AGUDA, LAGOS STATE

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Matriculation Number: 15PCK01079

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B Sc. (Electronic and Electrical Engineering) (Ile-Ife)

Matriculation Number: 15PCK01079

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (M.Eng.) DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING

JULY, 2017

ACCEPTANCE

This is to attest that this dissertation was accepted in partial fulfillment of the requirements for the award of the degree of **Master of Engineering** (M.Eng.) **Degree in Electrical and Electronics Engineering** in the Department of **Electrical and Information Engineering,** College of Engineering, Covenant University, Ota, Ogun State, Nigeria.

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DECLARATION

I, **AKINTOLA Adebisi Ayodeji** (15PCK01079) declare that this research was carried out by me under the supervision of Prof. C. O. A. Awosope of the Department of Electrical and Information Engineering, College of Engineering, Covenant University, Ota. I attest that the dissertation has not been presented either wholly or partly for the award of any degree elsewhere. All sources of data and scholarly information used in this dissertation are duly acknowledged.

Signed: ___________________________ Date: ____________________

CERTIFICATION

We verify that the dissertation titled "RELIABILITY EVALUATION OF SECONDARY DISTRIBUTION SYSTEM IN NIGERIA: A CASE STUDY OF AYETORO 1 SUBSTATION, AGUDA, LAGOS STATE" is an original work carried out by AKINTOLA Adebisi Ayodeji, (15PCK01079), in the Department of Electrical and Information Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria, under the supervision of Prof. C. O. A. Awosope. We have examined and found the work acceptable for the award of degree of Master of Engineering in Electrical and Electronics Engineering.

Prof. C.O.A. Awosope ____________________________

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

AENS Average Energy Not Served

ASAI Average Service Availability Index

ASUI Average Service Unavailability Index

CAIDI Customer Average Interruption Duration Index

ECOST System Expected Interruption Cost Index

EDNS Energy demanded but not supplied

HRC High Rupturing Capacity

IEEE Institute of Electrical and Electronics Engineers

$Jkg^{-1}K^{-1}$ Joule per Kilogram per Kelvin

kV Kilovolt

kVA Kilovolt Ampere

MDT Mean Down Time

MTBF Mean Time Between Failure

MTTR Mean Time To Repair

PHCN Power Holding Company of Nigeria

P.U. Per Unit

SAIDI System Average Interruption Duration Index

SAIFI System Average Interruption Frequency Index

λ expected failure rate

r average outage time

ABSTRACT

A power system is set up basically to meet the demands of the customers. However, interruptions which are largely unavoidable contribute to the unavailability of power and thus prevent power system from achieving this. In most cases, it is the sustained interruptions that greatly affect both the utility company and its customers. Hence, it is necessary to find means of determining which component failure contributes most to the unavailability of the distribution system, and how this unavailability actually affects the customers. This is to enable system planners and designers to seek better ways of improving the reliability of a typical secondary distribution substation system having a single-end fed radial configuration. By using analytical method and network reduction technique, the substation reliability was analyzed based on the outage data gotten from the utility company. The conclusion from this work shows that transformer failure followed by the fuse failure contributes most to the substation's unavailability. The overall system availability shows that the system's performance is poor.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Electric power system is basically set up to supply electricity with little or no interruptions to its customers. The number of interruptions that occur while the system performs its intended function is part of what determines the overall reliability of the system. The other factor that determines its reliability is the quality of electricity delivered. Furthermore, the capability of a power system to continuously deliver quality electricity means that the customers are satisfied and the electricity providers are having favorable returns on their investment as they continue their business of supplying electricity. As electricity consumption has become an important factor that affects the drive needed for technology to grow and to facilitate the development of modern society, it is very important therefore to take seriously the issue of reliability of an electric power system.

Generation, transmission and distribution are the three subsystems of an electric power system. At the generating station, electricity is generated and transmitted through the high voltage transmission lines to the distribution substations. The distribution substation system considered covers the electrical system between the substation fed by the subtransmission system and the supply line to the consumers' meters i.e. 11kV to 0.415kV transformation (Theraja and Theraja, 2005). The distribution substations are usually sited relatively near the customers for effective delivery, monitoring and maintenance of the substation and the customer end and are usually referred to as secondary distribution substation system. Distribution systems basically serve as the link from the distribution substation to the customer. Reliable and safe transfer of electricity to the customers covered by the distribution area is ensured by this system and is the main subject studied in this dissertation.

In terms of reliability evaluation and modeling, generating stations have justifiably received more attention than the other systems because they are individually capital intensive. In addition, in the event of generation inadequacy and generation loss there is usually widespread catastrophic effects on the society and environment. It impacts directly on the whole system and even distribution system will not be able to perform its duty because there will be no electricity to supply to customers. However based on published research work and studies, distribution systems have begun to receive moderate attention compared to past decades. In most cases, when there is disturbance in form of failure which results in outages in the distribution system it affects only the localized territory. Only in few cases does the fault move up in to the system largely as a result of protection failure. Analysis of the customer failure statistics of most electricity companies shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer (Gonen, 2014). In effect, the purpose of establishing generating stations and the hurdles overcome to transmit electricity is defeated when it does not get to the user end as a result of distribution system failure. This makes distribution system to be highly important. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability (Billinton and Jonnavithula, 1996).

Meanwhile, as the main aim of a power system is to meet the electricity needs of the customers and this can only be achieved when the components making up the system are performing their intended function properly for as long as the system is in operation, it is important that the demand for electricity and its supply be properly viewed and included in setting up the system. Therefore, due to its high impact on the cost of electricity and its corresponding effect on customer satisfaction, distribution reliability is very important. However, as in any other viable engineering system, there are challenges that face power distribution system which tends to make the system unreliable. One of these is the issue of serving its main purpose which is to supply quality electricity with little or no interruptions. This problem is inevitable in power systems across the world but the way they are managed is what makes it different from country to country. For instance in the United States, there is nearly an uninterrupted delivery of quality electricity to its numerous customers which makes it rank among the most dependable in the world. It is in management of the power systems that reliability evaluation becomes significant. Reliability evaluation does not in any way make a system more reliable but it helps in system planning and identification of weak components.

1.2 PROBLEM STATEMENT

A distribution substation consists of supply line, power transformer, outgoing feeders, switching device, and protection device to ensure efficient operation. 11/0.415kV substations are common sight on streets and perform the function of distributing power supply to a number of customers in a given neighborhood. The substation is the final stage of electric power distribution system as the circuits leaves the substation at 415V and delivered by three-phase, 4-wire system. The voltage between any two phases is usually lower than the actual 415V and between a phase and neutral is 240Vand most times when measured is less than 230V as a result of voltage drop.

In Nigeria, daily electric power interruption is largely becoming a consistent phenomenon in wide area network of electricity distribution and this is basically due to insufficient power generation, transmission faults and distribution system faults and failures. Unavailability of power supply to customers can occur several times a day and sometimes for weeks and in worst cases for months. There are instances where several interruptions occur in a day especially at the residential loads, which causes untimely failure of home gadgets, darkening of light bulbs, and reduced efficiency and performance of high-power appliances. Damage of electronic devices and burning of light bulbs have also occurred due to over voltages. There are also few cases of deliberate outages due to weather especially rainfall. This is to protect most residential areas from voltage surge that may enter into the power system when lightning occurs owing to the fact that not all residential areas were inspected and certified by the electrical companies when the buildings were completed. Most electrical designs in residential houses are usually not done by professional engineers especially in the middle-class and low-income earner's settlements.

Considering the fact that the presently installed capacity in Nigeria cannot serve all the customers, it is incumbent that the available power generated be judiciously served with little or no interruptions. That is, when power is generated and available in the system, the distribution subsystem must be up to its task of delivering quality power to the customers. Hence there is the need for the reliability evaluation of a typical distribution substation and its availability.

In the reliability evaluation of power systems, the collection of failure data could be one of the most difficult things because of several reasons (Wang, 2012). Hence, one of the reasons the study area is chosen because of access to the data needed for this project. Also, the substation supplies relatively large customers which makes outage in the substation a major concern for both the Power Company (Eko electricity) and customers, Ayetoro 1 Substation, Aguda . In addition, the features of the substation is as highlighted below and can be found in many other substations which have been in service for more than 10 years across the country.

i. It’s an outdoor substation with overhead lines and transformers mounted on the ground. Thereby, exposing most of the components to different weather conditions.
ii. The HRC fuse that serves as major protection device for the transformer has been replaced with copper strands which are easily replaceable. The size of the strand is usually determined by the utility technical workers.
iii. It has relatively large number of customers of which some cannot be accounted for when billing is done.
iv. Most of the substation components have undergone several repairs due to random failures.

1.3 AIM AND OBJECTIVES

The aim of this dissertation is to conduct a reliability evaluation of secondary distribution substation system in Nigeria: a case study of Ayetoro 1 substation, Aguda Lagos state. The specific objectives of the dissertation to drive the above stated aim are to determine

a. the reliability of each component in the substation system.
b. the overall reliability of the distribution substation.
c. how the substation unavailability contributes to the loss of supply to the customers by interpreting the results obtained after analysis.

CHAPTER 2

LITERATURE REVIEW

2.0 OVERVIEW

Power systems across the globe are built with the intent of providing for the energy needs of the modern times. Hence, it is understood that meeting the needs of the customers is the most important reason why a power system is established, with the profit coming along while doing the business. The significance of a reliable distribution is hinged on the fact that even if the generation and transmission of a power system are highly reliable, an unreliable distribution system will mean that there will be poor supply of energy to the customers. Hence, this chapter looks at the principle behind reliability and also explains the different methods available in order to carry out assessment of a power distribution system. In addition, critical literature review of current research papers was carried out in this chapter.

2.1 RELIABILITY PRINCIPLES

Reliability of an electric power system is the probability that the system will continuously deliver electricity to its consumers without compromise on the quality of the power being delivered (Bhavaraju et al., 2005). It is also simply a measure of whether users have electricity when it is needed (Wang, 2012). Equipment outages and consumer interruptions are the primary focus of distribution reliability. In normal operating conditions, all components in the distribution substation (except standby) are energized and by implication all customers are energized. Furthermore, according to IEEE, the definition of reliability is simply the ability of a system or component to perform its intended functions under stated conditions for a specified period of time. Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired (Kueck et al., 2004)

Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages of the components in the system and interruptions to power supply. The unscheduled events may be as a result of oversights during installation or maintenance operations, component failures and faults. The scheduled events are usually as a result of the need to carry out maintenance operations on the equipment, construction, consumer request, and usually consumers do get notice of interruption of supply in advance.

2.1.1 Different Types of Interruption

There are different types of interruption and they are as discussed below.

2.1.1.1 Momentary Interruption

This is a situation where a customer is without electricity supply from the utility for less than a few minutes. When power supply is interrupted and restored in less than 5 minutes, then the customer is said to have experienced momentary interruption according to IEEE 1366-2003 standard. The operation of a circuit breaker or reclosers, which opens the circuit momentarily to clear faults and closes back, brings about this interruption. Momentary interruptions sometimes affect power quality and sometimes lead to voltage sags. (Short, 2004)

2.1.1.2 Temporary Interruption

This is usually categorized as interruptions that last a few hours. It is usually less in duration than a sustained interruption and higher than momentary interruption. This interruption usually requires an operator to put the system back on by manual operation. Hence, the duration is usually as determined by the unavailability of an operator to perform the switching operation immediately. This interruption is expected to last for less than two hours. Both momentary and temporary interruptions can be as a result of faults due to lightning, two conductors in contact when there is wind etc. (Gonen, 2014).

2.1.1.3 Sustained Interruption

This is a loss of supply to customer which is usually more than many hours and can sometimes last for days. A temporary fault can lead to sustained interruption if it is not taken care of as soon as possible. However, sustained interruption could be as a result of transformer failure, insulator failure, damaged wires etc.

2.1.1.4 Planned Interruption

This happens when deliberate action is taken on a component by removing it from service in order to carry out maintenance work or construction. This interruption usually accompanies scheduled outage. It is usually planned and the customers are aware of the loss of supply that ensues.

2.1.1.5 Unplanned Interruption

This type of interruption is basically as a result of faults and failures which makes a component to be unavailable to perform its function.

In addition, the two major factors that affect the reliability of power distribution system are Capacity shortages and Faults and failures

2.1.2 Capacity Shortages

The reliability of power systems is usually lowered by capacity shortage. This can be as a result of inability to meet market demands or inadequate planning to provide redundant element to ensure supply of power in case of unforeseen events. The situation above is sometimes caused when there is inadequate transmission or distribution capacity to ensure transfer of available electricity within the power system. For instance, the Transmission Company of Nigeria (TCN) is projecting an expansion of its wheeling capacity beyond the present level of 5,500MW to 10,000MW and 20,000MW by 2017 and 2020 respectively (Ezeolisah, July- December 2015). The achievement of the project mentioned above will solve the capacity shortage problem being discussed. This will impact directly on electricity available for distribution utilities to serve their customers. Moreover, there is interruption in the delivery of electricity when there is capacity shortage as utility managers perform load-shedding to avoid overloading the system which means that some customers will experience outages because their loads will not be served. In addition, for a distribution system, power delivery will be hampered by unexpected additions of load when new customers join existing network thereby weakening the system and affecting its reliability.

2.1.3 Faults and Failures

Faults occur when there is short circuit between phases, or phase to ground faults leading to unintended opening of fuses or circuit breakers used for protection within a power distribution system. A fault means that an accidental electrical connection is made between an energized component and something at a different potential leading to a short circuit (Meier, 2006). The failure of an electrical component is usually not influenced by external factors that may give rise to faults. Failures can be as a result of human error or due to malfunctioning of the equipment. There are several types of failure in electrical equipments and the common types that lead to short circuits include transformer windings, lightning arrestors, and high voltage bushings. Both faults and failures can cause outages which could last for few seconds if it is resolved quickly by operating programmed switching equipment. When an electrical component such as a transformer is damaged due to faults or failures, its replacement or repair usually takes time, sometimes hours or days and as such may lead to longer hours of service interruption to the consumers. In most cases, faults and failures instead of capacity deficiencies are the reasons for component outages in a power system.

2.2 RELIABILITY EVALUATION

Providing answers to questions such as, “how reliable is the system?”, “which component contributes most to incessant interruptions?” and “which part of the system requires more financial commitment to better the system operations?” are some of the main goals of reliability analysis (Dorji, 2009). Distribution system reliability can be divided into two general aspects, namely: System Adequacy and System Security.

System adequacy simply refers to static situation. It checks the capacity of the system to adequately deliver the energy demanded by the customers by carrying out evaluation based on the components or equipment being used. It simply implies that system adequacy focuses on the system design and structure and its installed component capacity (Billinton and Allan, 1996; Wang, 2012).

System security is the ability of the system to respond to any given contingency or disturbances such as faults (Billinton and Allan, 1996). Thence, the reliability that concentrates on the system security is called dynamic reliability, while the reliability that focuses on the system adequacy is defined as static reliability. The focus of this dissertation is on static reliability.

The two major methods used in carrying out the evaluation of distribution systems reliability are (Kjolle and Sand, 2002):

1. Analytical methods based on solution of mathematical models
2. Simulation methods based on drawings from statistical distributions

2.2.1 Analytical Method

In this method, the evaluation is carried out based on assumptions with respect to statistical distributions of repair times and failure rates. Failure mode analysis or minimum cut-set analysis is the most common evaluation technique using a set of approximate equations. Compared to the simulation method, analytical method is less time consuming but in most cases does not represent repair times adequately. This method is further divided into Network technique and Markov modeling.

2.2.1.1 Network Technique

An electrical system can be viewed as a network of its components connected together either in series, parallel, meshed or a combination of these. The structural relationships between a system and its components are considered in this technique. Modeling the failure behavior of the system is one of the major challenges in reliability analysis. However, according to Billinton and Allan (1996), analytical techniques of distribution systems and electrical networks when the generation sources are neglected are mainly based on a failure modes and effects analysis (FMEA), using minimal cuts sets and groups of equations for calculating the reliability indices of series and parallel systems. By carrying out analysis on each component that makes up the system, this approach presents all the imminent failure modes and then pin-points their resulting effects on the system. This method determines at least those components within a system which result in an interruption of service at the load-point of interest. This is the method used in the analysis of the components in the substation analyzed in this dissertation.

2.2.1.2 Markov Modeling

Stochastic modeling in reliability engineering is used to explain the functioning of a system with time. In most cases, the component failure and repair times are used as the random variables. A Markov model looks into the present event to determine the future event and does not consider the past event. In other words, the Markov model works solely on the assumption that a system behavior in each state is memoryless. It therefore does not consider the process or event that led to the present event. However it is possible to generate a stochastic system that is related and similar to the original system or event. This technique requires a large number of states to generate the system to be modeled. This is because as the number of factors/parameters increases, there is exponential increase in the number of states. Hence, various assumptions must be made to ensure a controllable sized model.

2.2.2 Simulation Technique

The behavior of a particular system could follow a random nature. Simulation in reliability analysis often concerns random events and are commonly referred to as Monte Carlo simulations. Simulation can be done using a sequential method in which events are chosen in a given order or random method in which events are chosen at random. In simulation, one of the aims is to make estimates of unknown parameters which will serve as real experiments after observing a simulation process for a specific period. The simulation process is intended for examining and predicting the stochastic behavior of a system in simulated time. This technique takes time and it is expensive to implement because of the need to use huge number of failures to simulate. The statistical distribution of failure rates and outage times gives the fault contribution from each component. In simulation process, a number of runs are normally performed by the software so as to find the estimates of the means of the output parameters needed such as failure rate, mean repair time, and availability. This is usually done to have a converging result since simulation generates variable outcomes. (O'Connor and Kleyner, 2011; Uhunmwangho and Omorogiuwa, 2014)

In a modeled system in which the events in the previous interval directly impact on the next interval, which is often the case in distribution system reliability studies where the action or inaction of one component may affect the performance of the other, then the sequential method is appropriate. In this method, events are set to occur at random times to obey specific probability distributions. The actual behavior of the system is represented by distribution function gotten from the conversion of the random numbers used. The time-sequential simulation process can also be used to examine and predict behavior patterns in simulated time. This method is an extension of the sequential method, only that, it uses an artificial history of up and down times of the system and it is included in the generation of the random chronological number as in sequential simulation. The relationship that exists between the element states and system states serves as template to generate the component histories which help in formulating the sequence of in-service, out-of-service cycles of the system (Faulin et al., 2010).

2.3 RELIABILITY INDICES

Reliability indices are numerical parameters that reflect the capability of the system to provide its customers an acceptable level of electricity supply (Uhunmwangho and Omorogiuwa, 2014). By providing quantitative measures at different individual load points and for the whole system, these indices approximate system reliability. The most important of all the indices used in evaluation of power systems reliability are the duration of interruption and frequency of interruption. This is basically due to the fact that they indicate the expected frequency and the expected duration of interruption of power supply. The frequently used reliability indices for evaluation of systems include: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Average Energy Not Served (AENS), System Expected Interruption Cost Index (ECOST), and Energy demanded but not supplied (EDNS). Failure rate, annual unavailability, and average outage duration are the basic indices associated with system load points. By collecting information on the past performance of a system, valuable insight is provided into the reliability profile of the existing system. This dissertation covers a period of twelve months' data (January 2016 - December 2016), and was obtained from the Ayetoro 1 Substation, Aguda, Eko Electricity Company.

2.4 LITERATURE REVIEW OF CURRENT RESEARCH PAPERS

Reference (Onime and Adegboyega, 2014) carried out reliability assessment of power distribution system in Nigeria using Ekpoma network, Edo, as a case study. Outage data were collected for January 2012 to December 2012 and the average availability using basic reliability indices was evaluated for Iruekpen, Irrua, and Express feeders which are distribution feeders in Ekpoma. The reliability indices used include: Mean Time Between Failure (MTBF), Mean Down Time (MDT), and Availability. Customer-based indices used include: Customer's Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI) and the Average Service Unavailability Index (ASUI). The outages were classified based on type, frequency and durations and the result calculated showed that outages occur in the distribution feeders daily. Earth fault, supply failure, planned outage for maintenance, and load shedding were identified to be the possible causes for interruptions on the feeders. From the study, load shedding was the major reason for interruptions. The study further showed that heat during the dry season and windstorms in the rainy season were factors that could increase the failure rate of the feeders. The authors identified load shedding as the main cause of outages for the feeders analyzed. Planned outages due to maintenance work, supply failures and earth faults were also identified as causes for interruptions on the distribution feeders. The authors made case for improvement of the reliability of the distribution but did not give any recommendations that can bring about this improvement. There were no interpretations for the values of the customer orientation indices computed with reference to reliability benchmark. However, the system has an ASAI value of 0.6147 which means the reliability is very low.

The paper presented by (Adegboye and Dawal, 2012) investigated and discussed the faults that impact a typical 11-kV feeder in the Southern part of Kaduna city. There are four outgoing feeders from the 30-MVA, 33/11-kV Peugeot injection substation and Coca-Cola feeder is one of them. The reliability of the case study, 11-kV Coca Cola feeder, was assessed by analyzing the data gotten from the Power Holding Company (PHCN). The data collected was for January 2004 to December 2004 and it contains the type of fault, monthly peak load demand, outage duration, and power losses due to the outages on the feeder. The faults identified were earth fault and overcurrent faults. The earth fault however, contributes more to outages than overcurrent fault and its occurrence is higher during the rainy season than in the dry season. Hence, it was shown that the seasons of the year really affect the integrity of the substation. Amongst the many recommendations given in order to improve the reliability of the substation is that the distribution system's configuration should be redesigned to include ring system which means the consumers will now be supplied by two feeders. This thus removes dependency on just a single feeder. Also, iron cross arms should be used in place of wooden cross arms in order to reduce avoidable earth faults due to broken wooden cross arms. The paper only looked at the feeder distribution system and hence faults and failures that arise from the downstream of the secondary distribution were neglected.

The reliability of secondary distribution substation is significantly affected by outages as a result of faults. According to (Short, 2004), animals come second to trees as causes of fault which lead to outages in overhead distributions. For instance, short circuit as a result of animals such as lizards and rats entering the control panels, leads to overcurrent faults. In their paper, Min Gui et al., (2009), suggested a model for computing the weekly animal-related outages which will help utilities to monitor its performance trends from year to year. By combining wavelet transform techniques and the outputs of neural networks in their work, the models that can estimate weekly animal-caused outages were presented. In most cases, neural networks have overtraining problem and this was overcome by introducing a hybrid approach that integrates Artificial Immune System (AIS). The AIS was used for hypermutation and retraining of the networks and it's an emerging field of computational intelligence. The performance of the model was improved by this hybrid approach while positing that the accuracy of the models can be increased by spatial aggregation. This paper is essentially useful in helping to track the impact of animal-related outages. It however does not provide ways to minimize outages by animals.

As a result of their exposure to the atmosphere, the performance of overhead lines in a distribution system is drastically affected by weather. Line faults can be due to lightning, wind, and other weather factors. Also, frequent interruptions can be as a result of tree branches coming in contact with the lines. Therefore, reducing these forms of interruptions will improve the reliability of the distribution system. In their paper Gupta et al. (2005), the failure rates of overhead lines as a result of carefully chosen inputs were predicted using an adaptive fuzzy model. The paper presents an adaptive fuzzy modelling methodology to calculate the effects of wind, lightning, tree trimming and tree density on distribution lines. In order to train the system, data for a period of seven years were obtained from an existing utility. The information included in the data include: type of interruption, date of failure, possible cause and location of failure, number of consumers interrupted, number of feeders, duration of sustained interruption, and protective devices used in clearing faults. This model used the field observations of the selected inputs for few feeders and the resulting numbers of failures as a result of these inputs were recorded. The selected inputs were wind index, lightning, tree density and tree trimming while the output was failure rate. The operation of the model was checked by observing the absolute average error and root mean square. The effectiveness of the trained model was evaluated by carrying out sensitivity analysis. The major problem with this methodology is the large size and quality of data needed. However, with the use of outage management systems (OMS) and geographical information systems (GIS) utilities can provide the data needed.

By using NEPLAN simulation software, a software tool that helps in assessing the configurations of power system, in the paper by Uhunmwangho and Omorogiuwa (2014) a method is presented for evaluation and prediction of distribution system reliability using Choba in Rivers state as case study. NEPLAN power system software was used to perform an offline simulation of the distribution network considering outage time, incoming energy, outgoing voltages (kV) rating and three-phase current rating. The data for a period of six months was obtained from the Choba Injection substation and used to compute the reliability indices of the distribution system. Customers Average Interruption Duration Index (CAIDI), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Frequency Index (CAIFI), Customer Interruptions per Interruption Index (CIII), Momentary Average Interruption Frequency Index (MAIFI) and Average Service Availability Index (ASAI) were used in estimating the reliability of the system. The result of the computed reliability indices showed that the distribution system averaged an availability of 99.98% which the authors described as being very poor due to the fact that other utilities have set an ASAI goal of 99.99%. It was recommended that the utility company should be keeping detailed account of data and records which contains component outage time, component failure rate and total energy consumed which will help compute reliability indices such as Energy Demanded Not Supplied (EDNS).

Most distribution systems are affected by outages which could be as a result of weather, vegetation and animals. Furthermore, it is quite impossible for utilities to completely shield its equipment from these factors. The paper (Okorie and Abdu, 2015) presents a reliability evaluation of outage data obtained from utilities in Kano Distribution Company of Power Holding Company of Nigeria PLC (PHCN). Emphasis of the study was on 33-kV feeder distribution system which included overhead distribution network and underground network systems. The authors carried out a thorough analysis on the causes of outages in order to study the pattern in the outages and determine the most significant cause of outage. Exactly 36 stations/service areas in Kano metropolis and the year 2011 and 2012 as base years were used for this evaluation. The reliability indices used in this study include: System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Average Service Availability Index (ASAI). The authors noted that large number of outages was reported in the data as unknown or other causes due to the inexperience of the utility workers. This means a larger number of the outages could not be assigned to a particular cause and this will impact the result gotten by the study. It is therefore important that workers should be trained to be able to identify the causes of outages as this will aid the better and accurate data collection by utilities. More so, the authors suggested that there should be standard way of reporting outages in utilities. The study shows that environmental factors contributed to more than 50% of the outage in the distribution system. The other causes are earth faults, maintenance, unknown and operation. Based on the content of the paper, the justification for the conclusion was not found or included in the paper.

Reference (Okorie, 2016) assessed and quantified the reliability performance of Abakpa distribution substation of Kaduna Disco. In addition, the author suggested ways of achieving better reliability performance. The distribution network was assessed with filed data collected from the substation's logbooks for a period of three years, 2010-2012. The substation's failure rate, outage rate, and repair rate were computed by using the duration and frequency of outages in the data. The following reliability indices were also computed: Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), Mean Time To Failure (MTTF), Availability and Reliability. The load outages and downtimes for each year were summed up for each year in order to avoid working with cumbersome data due to the large data involved. It is important to note that the Abakpa substation is a 132-kV/33-kV/11-kV transmission and distribution substation. The cumulative fault frequency, period of occurrence and total downtime for each year were computed and used to calculate the reliability indices mentioned earlier. The reliability indices were computed for components and for nature/causes of failure for each of the year understudied. Examples of the component faults include: earth leakage fault, switch gear related fault, fault tripping fault, faulty transformers, tree falling on line, failure on line due to jumpers, reactor faults, overcurrent etc. The result showed that contrary to one of the objectives of the paper, the author failed to suggest a distribution network design that will improve the reliability of the substation while it mentioned that simple overhead radial systems have poor reliability performance. The paper, however, discussed some of the factors that influence reliability such as vegetation, animals, and environmental factors. Circuit length was also pointed out as a factor that affects reliability as longer circuits are susceptible to interruptions.

According to Billinton and Alan (1996), reliability can be increased by increased investment bringing about a decrease in the utility outage cost of the system. This outage cost can usually be computed by multiplying the energy cut to the consumer by the cost of the kWh not supplied. By employing analytical technique, the study carried out by Izuegbunam et al., (2014) assessed the reliability of Onitsha Business Unit within the period of three years, 2009 to 2011. This technique requires the use of outage data which was obtained from the Power Holding Company (PHCN) for the various feeders in the

Onitsha distribution system. The paper also presented the impact of having photovoltaic (PV)/inverter interconnected with the network in order to improve the reliability of the system. The authors investigated the factors causing poor reliability performance, and possible ways to bring about improvements to the system. In the paper, the system reliability indices computed include: Average Failure Rate at Load point, Annual outage duration at Load Point, Average outage Duration at Load Point, System Expected Energy Not Supplied (EENS), System Expected Interruption Cost Index (ECOST), Interrupted Energy Assessment Rate Index at Load Point (IEARN), Average Energy Not Supplied Index (AENS), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), and Average Service unavailability Index (ASUI). To analyze the effect of improving the reliability of the system by having alternative or complementary source (PV/inverter) interconnected at the 11-kV busbar, ETAP software was used. The algorithm used in the software was displayed and the simulation was carried out with a set-up having a self-driven fixed frequency inverter design connected to 11-kV distribution bus to supply the loads whenever there is outage in the utility. The results obtained showed 61.2%, 55.7% and 65.1% reductions in revenue loss for 2009, 2010, and 2011 respectively after the PV installation. The cause of the substation's poor performance was not discussed in the paper though it was stated as part of the objectives. However, this paper has shown that reliability performance can be improved upon by introducing a complementary source and that by effectively utilizing solar technologies such as PV, there will be less erratic supply of power to consumers

The different techniques applied to evaluate reliability of distribution system planning studies and operations were reviewed by Lantharthong and Phanthuna (2012). The paper revealed that, reliability is an important element considered in ensuring effective design and functioning of electric power distribution systems and load. It posited that ensuring adequate planning, monitoring of system performance and putting in place effective control actions will enhance reduction in operation and maintenance costs due to low reliability.

Mohit and Ram (2013) took into consideration 66kV/400V substation for evaluation of several reliability indices by using the Boolean function technique and algebra of logics. The paper emphasizes that complexities in a system make reliability evaluation difficult to carry out. The Boolean function technique, which helps in simplifying complexities, was used based on some assumptions made on the particular substation for which mathematical model for measuring was developed. In addition, the failure rate and the mean time to failure were calculated and used for the substation reliability analysis.

Adefarati et al., (2014) presented a research work on the reliability assessment of Nigeria 330/132kV substations, using Ayede 330/132kV substation as a case study. In their work, the different reliability indices that can be used to determine optimum operation of a power system such as SAIDI, CAIDI, SAIFI, CAIFI, CIII, MAIFI and ASAI were deduced for the substation. Furthermore, their work reveals the necessity of optimizing power system failure rate since it affects availability, quality and quantity of electricity in the system. The analysis carried out looked into the criticality and sensitivities of the subsystems or components of the system for continuous improvement by analyzing only the substation feeders of the six districts being fed by it. The research further work presented suggestions on how to improve power system reliability.

Samuel et al., (2013) presented a research paper that assessed the reliability of a 132kV transmission line protection scheme using fault tree analysis. Their paper focused on the application of fault tree analysis to enhance the reliability of a power transmission line. Fault tree diagrams were developed for the present protection scheme employed on the 150km-long 132kVtransmission line in the Northern part of Nigeria of which Kano-Kankia power transmission line was used as case study. The protection scheme was analyzed and then compared with another newly developed scheme, by the authors, which has an arrangement that made provision for redundancy. The new scheme revealed a significant improvement of about 51% in the availability of the transmission lines. In addition, the assessment revealed that relays, as a result of lack of automatic supervision, were the major weakness of the protection scheme.

The paper presents a reflection of the 11/0.415 kV substations reliability at Ede town (Osun State, Nigeria), covering a period from March 2014 to February 2015. The findings serve as an aid to facilitate proper monitoring, maintenance and upgrade of substations. In this research, the distribution system reliability of the substations was analyzed using the different reliability indices. The data collected was used to evaluate the reliability indices of each substation under the study and the result shows that different customers experience different levels of reliability and availability of supply even if they are under the same feeder and/or substation. (Johnson, 2015)

The paper by Jibril and Ekundayo (2013) analyzed the reliability performance of the 33kV Kaduna Electricity Distribution Feeders, Northern Region, Nigeria. The monthly reliability parameters for the 33kV distribution feeders were calculated using the daily outage data of the feeders for 16 months (January, 2011 to December, 2012). The results of the analysis carried out show that the system availability is low compared to the IEEE standard of ASAI which is 0.99989.

Sonwane and Kushare (2015) presented an overview of useful methods used in reliability analysis. In reliability study of distribution system development of accurate and consistent models to represent system behavior is always a main concern to researchers. In this paper, an overview is carried out for distribution system reliability for various substation configurations. Various reliability indices and reliability cost mentioned in literature are discussed in the paper.

The inclusion of aging components when using conventional reliability analysis as a means to better the reliability evaluation of distribution network was done by Wang and Wu (2011). The analysis carried out presented the relationship between aging components and their limit age (time). Failure Mode and Effect Analysis (FMEA) was used to calculate the reliability indices. A simple distribution network was generated and used for the research and the focus was on supply lines.

The stochastic nature of failures of a distributed generation was analyzed with the distribution system using a method based on Bayesian Networks was a paper presented by Gao et al. (2014). The reliability analysis of the distribution system was done using test data from another research work. The analysis carried out determined the availability, location and the numbers of distributed generation and the effect it has on the overall distribution system performance.

An overview of the distribution system planning model used by Norwegian utilities with emphasis on the approach used for reliability analysis, RELRAD (reliability in radial systems), was presented. The use of RELRAD is placed within the framework of distribution system planning. Two case studies of typical Norwegian MV systems were included: the benefit of automation and remote control in a rural overhead system and the impact of reserve cable in an urban cable system (Kjolle and Sand, 2002).

2.5 SUMMARY

In this chapter, reliability was defined and the different types of interruptions were discussed. Also, the factors that affect the reliability of power distribution system were discussed. Distribution reliability evaluation was divided into two aspects and the two main methods used to carry out reliability evaluation were discussed. The later part of this chapter gave a critical review of published current research papers on reliability evaluation.

CHAPTER 3

METHODOLOGY

3.0 OVERVIEW

This chapter deals with the reliability and unavailability evaluation of distribution system. The approach presented can be used in manual calculations or included in a digital computer program. Quantitative technique, which involves collection of data, is used for the project. This technique describes the historical performance of existing systems and utilizes the historical performance to predict the effects of changing conditions on system performance. The reliability indices of the present system shall be evaluated by making use of the twelve month's data collected on the system. The reliability indices to be evaluated are explained and the formulae to be used are shown. Failure in the system is unavoidable; however, the effects could be lowered by carrying out proper analysis and planning which is also the reason for evaluation. In this project, analytical method namely, network modeling will be used.

3.1 OBJECTIVES

The major objective of this dissertation is to provide reliability analysis and availability of Ayetoro1 distribution Substation as a case study. This is to show that distribution substation heavily impacts the efficient delivery of electricity to customers. This therefore provides sound information to power system engineers in order to enhance better substation design and planning for system adequacy and ultimately, system security. Moreover, radial distribution system is what is in operation in Nigeria. Hence, the analysis carried out is to furnish a radial configuration. Radial systems are made up of components connected in series. In this system, the components making up the system are required to be functioning in order to ensure delivery of electricity from the substation to the customer end.

3.2 RELIABILITY ASSESSMENT, METRICS AND INDICES

Distribution substation system serves as the interface between utility companies and the customers served. Hence, its assessment helps to determine how reliable the system is and to what extent customers are being served. The ability of a distribution system to perform its function under stated conditions for a given period of time with little or no interruptions to service delivery is known as distribution reliability (Krish and Short, 2008).

Distribution reliability usually involves critical analytical handling of well defined metrics also known as units of measurement. Across the world, reliability indices are being used by utility companies to monitor the performance of their distribution region, and or the substation. Most utilities owned by investors are usually required by regulation to report their reliability performance as enumerated by reliability parameters. In most cases, this is done in order to reward utility companies that perform well as the trend in regulation is tending towards performance-based appraisal. Some of the utilities even pay bonuses to their managers based in part on reliability achievements (Dorji, 2009). Moreover, some commercial and industrial customers request for reliability indices from utility companies when planning to find a site for their firms. In addition, one thing that makes distribution system reliability very important is that, carrying out individual physical assessment on all installed equipments in the system would usually be physically tasking, expensive and time consuming.

3.3 RELIABILITY ANALYSIS

Reliability analysis of electrical distribution system is viewed as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans that, cost wise, were comparable considering system investment and cost of losses (Billinton and Allan, 1996).

There are two major methods employed in the analysis of distribution system reliability, namely Simulation method (Monte Carlo) and Analytical methods. The Monte Carlo technique usually takes time as a result of the huge number of inferences needed to arrive at precise results. The analytical approach is centered on statistical distributions of the rate of component failure and time taken to restore it to service. The method that is most often used in evaluating reliability indices is analytical approach which is based on failure modes assessment and the use of equations for series and parallel networks. The common indices used for evaluation: the expected failure rate (λ), the average outage time (r), and the expected annual outage time/ unavailability (U) which are suitable to the simple radial system. Distribution systems contain grids which are either radial or meshed. These networks are for the most part operated radially and this makes them simple to assess. The process is further complex for other network configurations. The main theory for reliability analysis used in this dissertation is discussed below.

3.3.1 Network Modeling

An electrical system can usually be viewed as a network of its components connected together either in series, parallel, meshed or a combination of these. The structural relationships between a system and its components are considered in this technique. Modeling the failure behavior of the system is one of the major challenges in reliability analysis. Hence, failure mode and effect analysis (FMEA) has become the widely accepted means for reliability evaluation of distribution systems. By carrying out analysis on each component that makes up the system, this approach presents all the imminent failure modes and then pin-points their resulting effects on the system. This method determines at least those components within a system which result in an interruption of service at the load-point of interest. This is the method used in the analysis of the components in the substation analyzed in this dissertation. It determines the load-point indices and aggregates them to get the system wide indices. A radial system basically consists of set of series components such as breakers, lines, switches, transformers and at the end "Customers". (Anthony, July 2014)

3.3.2 Series System

From reliability viewpoint, all the components in a series system must be working together to ensure system success or the failure of one leads to entire system failure. This therefore implies that a series system is a non- redundant system. The figure 3.1 below describes a series system:

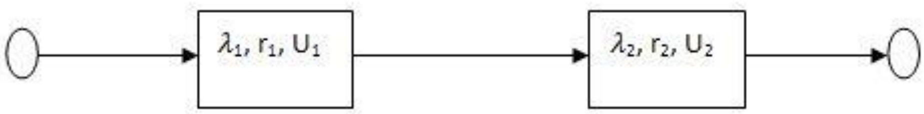

Figure 3.1 Typical Diagram of a Series System

Dorji (2007) provided the formulae used in the calculations involved in the series system shown in the figure 3.1 above and are given in equations (1) to (3);

where, λ = the expected failure rate

U = the annual outage time

r = the average outage time

$$\lambda_s = \lambda_1 + \lambda_2 = \sum_{i=1}^{2} \lambda_i \tag{1}$$

$$U_s = \lambda_1 r_1 + \lambda_2 r_2 = \sum_{i=1}^{2} \lambda_i r_i \tag{2}$$

$$r_s = \frac{U_s}{\lambda_s} \tag{3}$$

3.3.3 Parallel System

The components in a set are said to be in parallel from a reliability point of view if only one needs to be working for system success or all must fail for system failure. This is a fully redundant system.

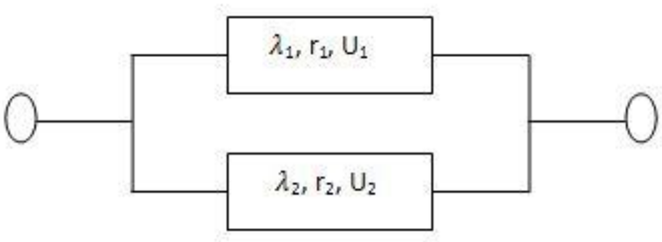

Figure 3.2 Typical Diagram of a Parallel System

The calculations involved in the parallel system shown in the figure 3.2 above are given in equations (4) to (6);

$$\lambda_p = \lambda_1 \lambda_2 (r_1 + r_2) \tag{4}$$

$$U_p = \lambda_1 \lambda_2 r_1 \tag{5}$$

$$r_p = \frac{U_p}{\lambda_p} \tag{6}$$

The above equations (1) to (6) are sufficient for simple radial systems and more indices are computed for general distribution systems. Network technique using the series system is used in calculating the failure rates of all components making up the distribution system.

Also, the following reliability parameters in equations (7) to (10) will be used in determining the availability of each component and the overall availability of the substation using the data collected.

Failure rate

$$\lambda = \frac{Number\ of\ outages\ on\ component\ in\ a\ given\ period}{Total\ time\ component\ is\ in\ operation} \tag{7}$$

Mean Time Between Failures (MTBF)

Mean time between failures (MTBF) is one of the basic ways of measuring the reliability of repairable components in a power system. It is the expected unit of time between the occurrences of two consecutive failures for repairable systems. MTBF is also the time that elapsed before a component, assembly, or system fails, under the condition of a constant failure rate. It describes the total time the component is in operation (Gonen, 2014). It is expressed as

$$MTBF = \frac{Total\ System\ Operating\ hours}{Number\ of\ Failures} \tag{8}$$

Mean Down Time (MDT) or Mean Time To Repair (MTTR): It is the average time it takes to identify the location of a failure and to repair that failure thereby restoring the component into normal operation. It describes the average time for which a component is out of service due to fault before it is restored to normal operation (Gonen, 2014). It is expressed as

$$MTTR = \frac{Total\ Duration\ of\ Outages}{Frequency\ of\ Outage} \tag{9}$$

Availability

Availability is the measure of the duration for which the component is in operation at any time. It deals with the duration for which the system is fully operational for its specific function (Gonen, 2014). It is expressed as

$$Availability = \frac{MTBF}{MTBF + MTTR} \qquad (10)$$

3.4 RELIABILITY INDICES

Reliability indices are statistical aggregations of reliability data for a well defined set of loads, components or customers. Reliability indices are often the mean value of a specific reliability feature for an entire system, operating region, or feeder. The sections below describe the most important reliability indices used by most utility companies and system planners. The indices have traditionally only included long duration interruption (interruptions longer than 5 minutes). A general way of determining reliability is by computing the customer and load-based indices (Gonen, 2014). Billinton and Allan (1996) provided the indices used in the calculations, equations (11) to (15), which Onime and Adegboyega (2014) also cited.

System Average Interruption Duration index (SAIDI)

This is defined as the average interruption duration for customers served during a specified time period. The unit is "minutes". This index helps the utility to report for how many minutes customers would have been out of service if all customers were out at one time. It is expressed as

$$SAIDI = \frac{Total\ Outage\ Duration\ in\ hours}{Number\ of\ Customers\ Supplied} \qquad (11)$$

System Average Interruption Frequency index (SAIFI)

This is defined as the average number of times that a customer is interrupted during a specified time period. The resulting unit is "interruptions per customer". It is expressed as

$$SAIFI = \frac{Frequency\ of\ Outages}{Number\ of\ Customers\ Supplied} \qquad (12)$$

Customer Average Interruption Duration Index (CAIDI)

This is defined as the average length of an interruption, weighted by the number of customers affected, for customers interrupted during a specific time period. The index enables utilities to report the average duration of a customer outage for those customers affected. It is expressed as

$$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ number\ of\ Customers\ Interrupted} = \frac{SAIDI}{SAIFI} \tag{13}$$

Average Service Availability Index (ASAI)

This is a measure of the average availability of the distribution system that serves customers. It is usually represented in percentages. It is expressed as

$$ASAI = \frac{Consumer\ Hours\ Service\ Availability}{Customers\ Hours\ service\ Demanded} \tag{14}$$

Average Service Unavailability Index($\boldsymbol{ASUI}$)

It provides the fraction of time customers are without electricity throughout the predefined interval of time. It is expressed as

$$ASUI = \frac{Duration\ of\ Outages\ in\ Hours}{Total\ Hours\ Demanded} \tag{15}$$

3.5 COLLECTION OF DATA

The data collected was for twelve-month component outage duration. Outages recorded in the utility outage logbook were as a result of customers' complaints to the utility company. The substation system, like other substations in Nigeria, does not have intelligent devices that can alert the distribution company whenever there is failure of any equipment or any form of interruption to the delivery of electricity to the customer. Only forced outages, outages due to faults and failures, were taken into consideration for this dissertation work to avoid extraneous circumstances. Outages due to scheduled maintenance and load shedding were not taken into consideration. This is so because scheduled outage or load shedding in the substation is intentional and cannot be attributed to any component failure which makes it hard for analysis to pin-point weak component if used. The dissertation focuses on the substation's inability to deliver electricity as a result of its own deficiency when there is electricity available for distribution. The raw data collected is placed in appendix A.

3.6 SUMMARY

In this chapter, a detailed explanation of the method used in this dissertation was given and the different formulae used in driving the objectives highlighted in this work were also shown. The different reliability indices used in this dissertation were also explained.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 OVERVIEW

This chapter presents detailed reliability analysis of the studied distribution system. The data collected from the selected substation is used to estimate the reliability indices of the components in the substation, the overall reliability of the substation and the customer reliability indices of the system.

4.1 DATA COLLECTED FROM AYETORO 1 SUBSTATION

The data of a period of twelve months from Ayetoro 1 substation (refer to Appendix A) was collected. The components on which data was collected are:

i. Transformer: 3-phase 11/0.415kV, 500kVA
ii. Circuit breaker: 11kV, 550A
iii. Switch gear 350A
iv. HRC fuse 350A
v. Incoming feeder 11kV, $902Jkg^{-1}K^{-1}$
vi. Outgoing feeder 0.415kV, $902Jkg^{-1}K^{-1}$
vii. Overcurrent relay 5/1A
viii. Earth fault relay 5/1A,
ix. Switches (3) 25A
x. Bus bar 630A, 11kV
xi. Surge arrester 11kV

And as earlier stated, the data reflects permanent outages as a result of faults and failures. The data also captures the recorded monthly duration for each component's outage and the frequency of the outages.

4.2 BASIC DESIGN LAYOUT

The distribution substation on which the study is carried out forms an integral part of a basic distribution network and it is mostly referred to as secondary distribution substation or customer substation. The primary distribution network which usually consists of an 11-

kV outgoing line supplying the secondary distribution substation has different types of system configuration. This includes single-end fed, double-end fed and closed ring network. Amongst the three configuration types, the ringed network has the lowest possible supply unavailability (Chan, 2001).

The typical configuration used in most distribution substations owned by PHCN is the single-end fed network which has overcurrent and earth fault protection upstream and the secondary substation normally has step-down transformer usually protected by HRC fuse. In some other designs, the secondary substation may include ring main units and high voltage circuit breaker. The single-end radial fed arrangement has the lowest supply security as outage of any component results in the loss of supply to the customers although it has the benefit that it can be easily coordinated, no idle part and it is relatively cheaper to implement. This implies that whenever there is fault or failure, the restoration of supply to the customer is dependent on the repair time of the fault and it greatly affects the reliability of the distribution substation. Figure 4.1 is a line diagram of a single-end radial fed configuration.

4.3 MAJOR CAUSES OF INTERRUPTION IN DISTRIBUTION SUBSTATION

When considering component failures leading to failures in the substation, it is important to note that the failures are usually categorized into three using the famous bathtub curve namely: teething failure, random failure and aging failure (Zhang, 2007). Amongst the three, random failure is the main failure of electrical components and usually caused by external factors such as lightning, tree-felling, and earthquake. This failure is mostly assumed to be constant and not really dependent on aging of the electrical component. Teething failure also described as the infant mortality or break-in period failure may be as a result of wrong installation of the component, improper handling while installing, or damage that occurs when it is being transported and sometimes production faults (Brown, 2009). It is usually taken care of either by repairing or replacing before installation. Hence, its impact on the component is reduced over the time of operation.

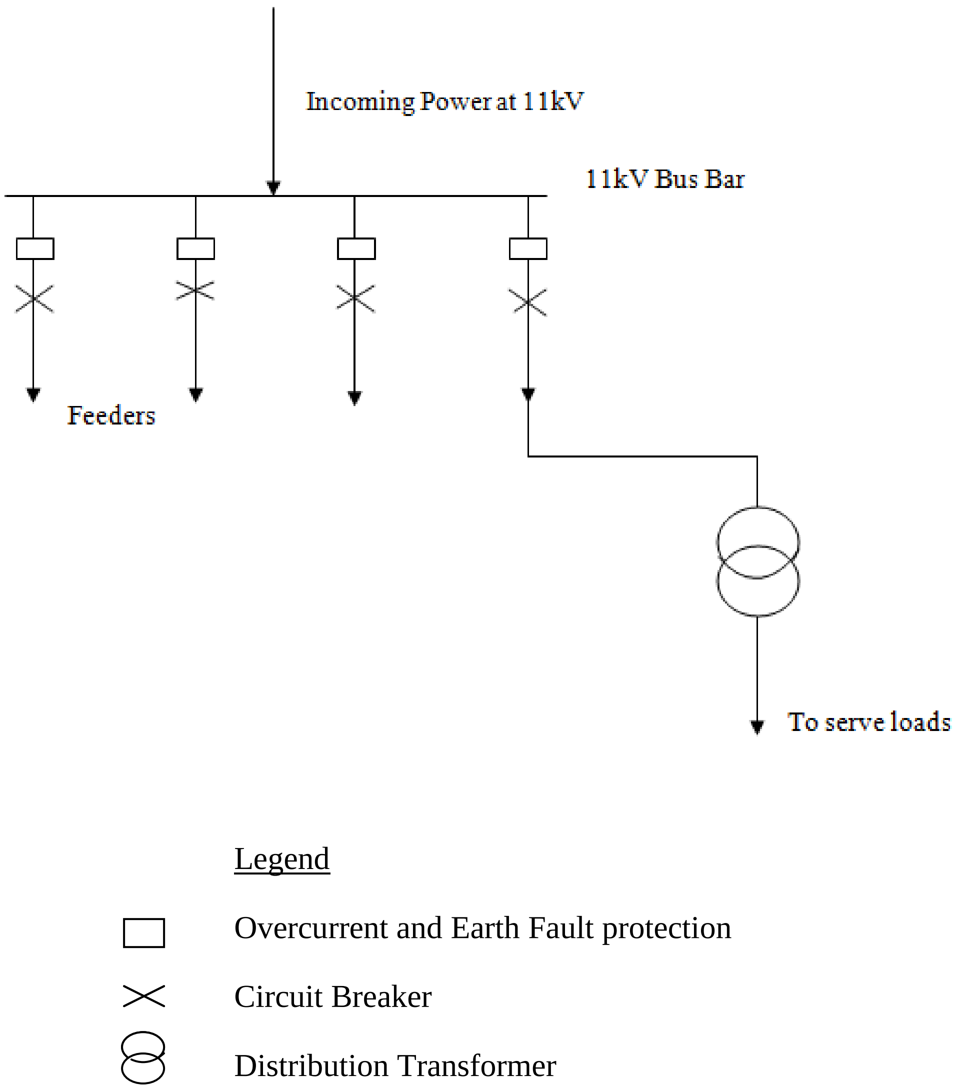

Figure 4.1 A Typical Single-End Radial Network Configuration

Ageing failure is typically as a result of decline in the strength of a component i.e. both mechanical and electrical strength.

In order to enhance the understanding of distribution substation reliability, it is incumbent that the basic causes of faults and failures within the substation are understood. The various major failure modes are discussed below:

4.3.1 Overhead Lines

In most distribution substation in Nigeria, overhead lines feed the substation and it also delivers electricity to customers while few make use of underground cables. The insulation material used in overhead lines and in underground cables is the main difference. Overhead lines are insulated by air which is an external factor and makes lines exposed to different environmental factors such as animals, weather etc.

One of the advantages of overhead lines is that it is not easily affected by high currents because the conductors are able to cope with temperatures higher than normal. That notwithstanding, the reliability of overhead lines is still greatly affected by high currents in many ways (Franc and Andrej, 2000). Conductors have their thermal limit hence when fault currents higher than the thermal limit is not quickly cleared, the conductor can melt and burn up. In addition, there is the increased chance of phase conductors swinging into contact when lines sag due to high current that may be as a result of overloading. Sometimes, higher currents make the wires to break as a result of reduced tensile strength. Actual wires contribute less to reliability problems in overhead lines as much as the energized auxiliary components such as cutouts, splices, switches and non-energized equipment such as poles and cross-arms (Brown, 2009).

In some cases, the incoming line is often affected by trees which may bridge two lines resulting in a possible fault if the tree is not removed early enough. However, when a branch falls on just a single line, it hardly leads to system faults.

4.3.2 Poles

Poles are structural elements needed to implement overhead distribution designs. They are conspicuous and can be easily tampered with by vehicular accident or wind. The safety of electrical wires on poles is the major reliability concern. When wind blows, it affects both the pole itself and the conductors. Laminated woods and cast concretes are the two types of pole majorly used and the wooden type is gaining popularity due to the fact that it is cheaper. In many cases, there are new attachments placed on existing poles which may mean that the pole may no longer meet wind loading criteria. Distribution poles need to be inspected and replaced when deterioration sets in. In some cases, the poles are bent as a result of wind force and left there. Too many wires and joints on a pole weaken it and when the pole is damaged, it directly impacts the lines leading to outage which however is sometimes not immediate.

4.3.3 Transformer

Transformer is a significant component in a distribution substation system and its failure sometimes takes a long time to repair or replace. Failures and overloads are two ways in which the reliability of distribution substation system is affected by transformers. Through fault weakens transformer insulation and it is the main reason behind transformer failures. Through faults are faults that happen outside the transformer but enter the transformer when there is protection failure. Failure can also be as a result of damaged seals and cracked insulators which can lead to outages. The load tap changer in a transformer can also lead to failure when, as a result of frequent operations, its mechanical parts become loose. Changing taps when a transformer is loaded makes the contact to overheat.

Most transformer ratings give room for temperature increase above the normal ratings. This is known as “hot spot temperature”. Hence, transformers can be overloaded only for a brief period when the temperature is between the normal temperature rating and hot spot temperature. Usually, overloading increases the transformer temperature gradually. Extreme overloads are dangerous because they lead to increase in temperature of the top oil which could cause tank rupture, oil overflow etc.

4.3.4 Circuit Breakers

Circuit breaker is a protective component in a distribution substation system which clears fault by opening the circuit without being damaged. As a protective device, it is needed to work properly all round the clock without failing. However, it is exposed to failure in several ways such as failure to open the circuit in the presence of fault, failure to close when fault has been cleared, failure due to internal fault as a result of mechanical wear out of parts, false tripping and so forth.

False tripping is mostly as a result of imperfect coordination with other protection devices like relays. And this can be minimized when other protection devices are well coordinated i.e. ensuring the relay settings are tested, and their protection zone is distinct. Damaged control wiring can also cause a circuit breaker to fail to open or to close. In some cases, circuit breakers can be stuck thereby leading to failure.

4.3.5 Lightning

Lightning is a natural phenomenon which affects distribution substation system by directly striking the power contacts and sometimes indirectly by striking objects in close range which induces a travelling voltage wave. In most cases, the latter happens when lightning occurs and its effect is less severe compared to direct strike. Usually, direct strikes are almost impossible to be protected against in a distribution system. Lightning surge arrestors are used to protect distribution system equipment from damage that might result as a result of induced high voltage caused by direct strikes. Furthermore, the body of the transformer which is solidly grounded and the neutral serves as lightning arrester ensuring protection against lightning in the distribution substation.

4.4 RELIABILITY EVALUATION OF THE COMPONENTS

The monthly component reliability indices for Ayetoro 1 substation were calculated using the formulae discussed in the previous chapter in a MATLAB code shown in Appendix B and C, and the results are shown in the Table 4.1 through Table 4.11. Each of these tables contains the computed failure rates for the components highlighted earlier. Table 4.12 contains the basic reliability indices such as the annual failure rate, average outage time and the annual outage time or unavailability. A graphical representation of these basic reliability indices is displayed in form of bar charts in Figure 4.2 to Figure 4.4.

Table 4.1: Summary of Outage Frequency and Duration on Transformer

Month	No. of Outages	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	10	186	744	0.0134
February	8	207	696	0.0115
March	4	38	744	0.0054
April	0	0	720	0
May	1	1	744	0.0013
June	0	0	720	0
July	0	0	744	0
August	2	14	744	0.0027
September	1	6	720	0.0014
October	0	0	744	0
November	1	6	720	0.0014
December	0	0	744	0

Table 4.2: Summary of Outage Frequency and Duration on Switchgear

Month	No. of Outages	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	13	24	744	0.0175
February	12	18	696	0.0172
March	7	9	744	0.0094
April	4	18	720	0.0056
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	0	0	744	0
September	0	0	720	0
October	0	0	744	0
November	2	8	720	0.0028
December	0	0	744	0

Table 4.3: Summary of Outage Frequency and Duration on Supply line (11kV)

Month	Frequency of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	3	10	744	0.0040
February	1	4	696	0.0014
March	0	0	744	0
April	5	17	720	0.0069
May	0	0	744	0
June	0	0	720	0
July	3	10	744	0.0040
August	0	0	744	0
September	1	5	720	0.0014
October	4	15	744	0.0054
November	2	9	720	0.0028
December	0	0	744	0

Table 4.4: Summary of Outage Frequency and Duration on Busbar

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	1	6	696	0.0014
March	0	0	744	0
April	0	0	720	0
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	1	8	744	0.0013
September	2	6	720	0.0028
October	0	0	744	0
November	0	0	720	0
December	0	0	744	0

Table 4.5: Summary of Outage Frequency and Duration on Circuit Breakers

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	0	0	696	0
March	0	0	744	0
April	2	13	720	0.0028
May	0	0	744	0
June	1	6	720	0.0014
July	0	0	744	0
August	0	0	744	0
September	0	0	720	0
October	1	3	744	0.0013
November	0	0	720	0
December	2	3	744	0.0027

Table 4.6: Summary of Outage Frequency and Duration on Fuse

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	9	14	744	0.0121
February	2	12	696	0.0029
March	5	17	744	0.0067
April	7	32	720	0.0097
May	3	12	744	0.0040
June	5	14	720	0.0069
July	5	18	744	0.0067
August	9	23	744	0.0121
September	0	0	720	0
October	8	35	744	0.0108
November	1	5	720	0.0014
December	0	0	744	0

Table 4.7: Summary of Outage Frequency and Duration on Switches

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	0	0	696	0
March	1	3	744	0.0013
April	0	0	720	0
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	0	0	744	0
September	1	6	720	0.0014
October	0	0	744	0
November	2	7	720	0.0028
December	0	0	744	0

Table 4.8: Summary of Outage Frequency and Duration on Outgoing Feeder (0.415kV)

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	3	26	744	0.0040
February	7	19	696	0.0101
March	2	9	744	0.0027
April	3	16	720	0.0042
May	6	11	744	0.0081
June	2	8	720	0.0028
July	2	16	744	0.0027
August	1	3	744	0.0013
September	4	10	720	0.0056
October	1	15	744	0.0013
November	5	12	720	0.0069
December	3	14	744	0.0040

Table 4.9: Summary of Outage Frequency and Duration on Overcurrent Relay

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	1	2	696	0.0014
March	0	0	744	0
April	1	0.5	720	0.0014
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	0	0	744	0
September	0	0	720	0
October	0	0	744	0
November	0	0	720	0
December	0	0	744	0

Table 4.10: Summary of Outage Frequency and Duration on Earth Fault Relay

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	0	0	696	0
March	0	0	744	0
April	0	0	720	0
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	0	0	744	0
September	0	0	720	0
October	1	2	744	0.0013
November	0	0	720	0
December	0	0	744	0

Table 4.11: Summary of Outage Frequency and Duration on Surge Arrester

Month	No. of failures	Outage Time (Hours)	Total Hour	Failure Rate (λ)
January	0	0	744	0
February	0	0	696	0
March	0	0	744	0
April	0	0	720	0
May	0	0	744	0
June	0	0	720	0
July	0	0	744	0
August	0	0	744	0
September	0	0	720	0
October	0	0	744	0
November	0	0	720	0
December	0	0	744	0

Table 4.12: Basic Reliability Indices on Each Component

Component	Failure Rate (f/yr) λ	Average Outage Time (Hours)	Annual Outage Time (Hours)
Transformer	0.0031	38.1667	0.1181
Switch gear	0.0044	6.4167	0.0280
Supply line (Incoming)	0.0022	5.8333	0.0126
Bus bars	0.00046322	1.6667	0.00077203
Circuit Breakers	0.00068324	2.0833	0.0014
Fuses	0.0061	15.1667	0.0927
Switches	0.00045923	1.3333	0.00061231
Outgoing feeder	0.0045	13.2500	0.0593
Overcurrent relay	0.00023547	0.2083	0.000049057
Earth fault relay	0.00011201	0.1667	0.000018668
Surge Arrester	0	0	0

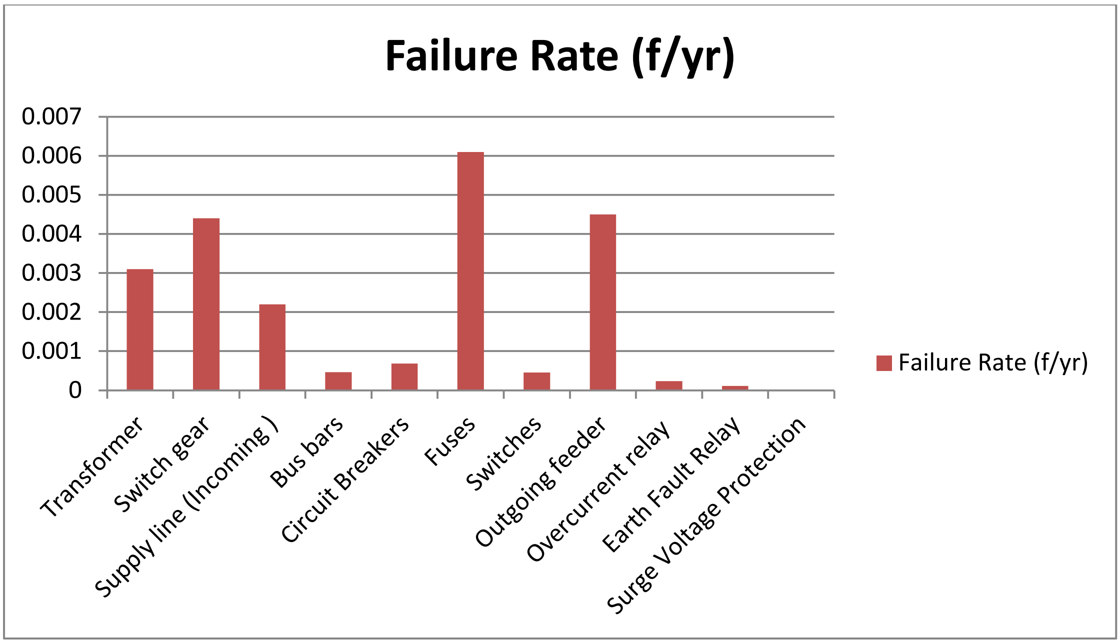

Figure 4.2: Bar Chart Showing the Failure Rate of Each Component

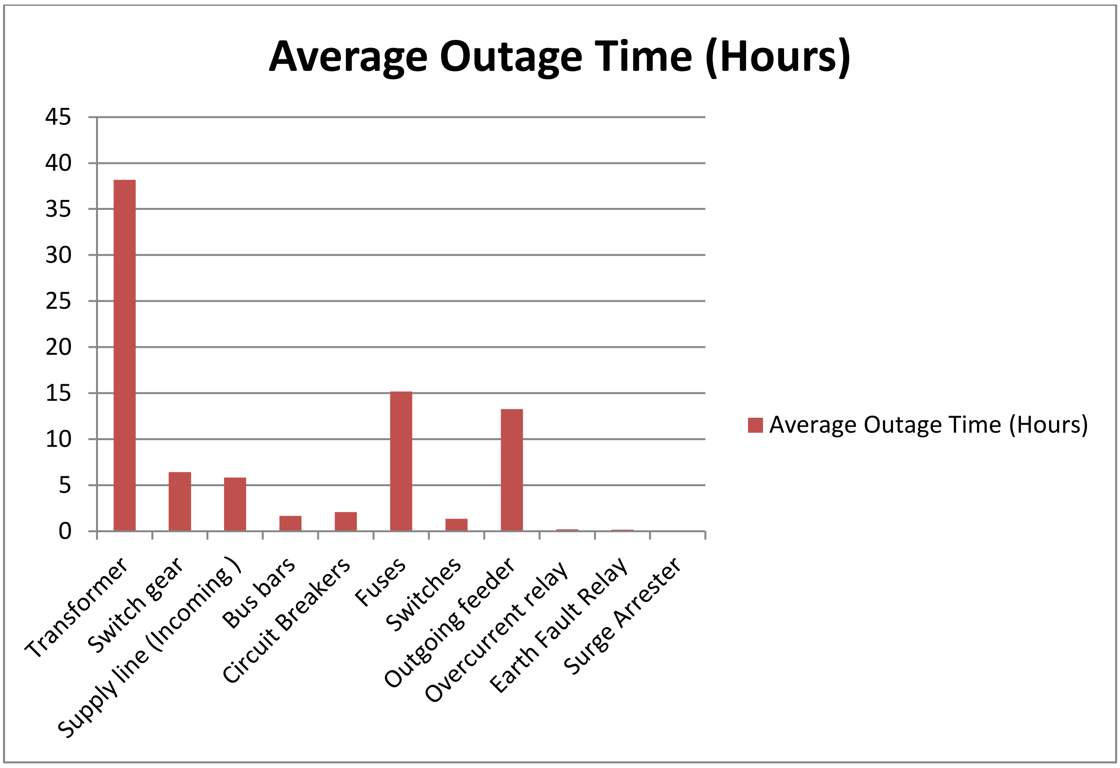

Figure 4.3: Bar Chart Showing the Average Outage Time of Each Component

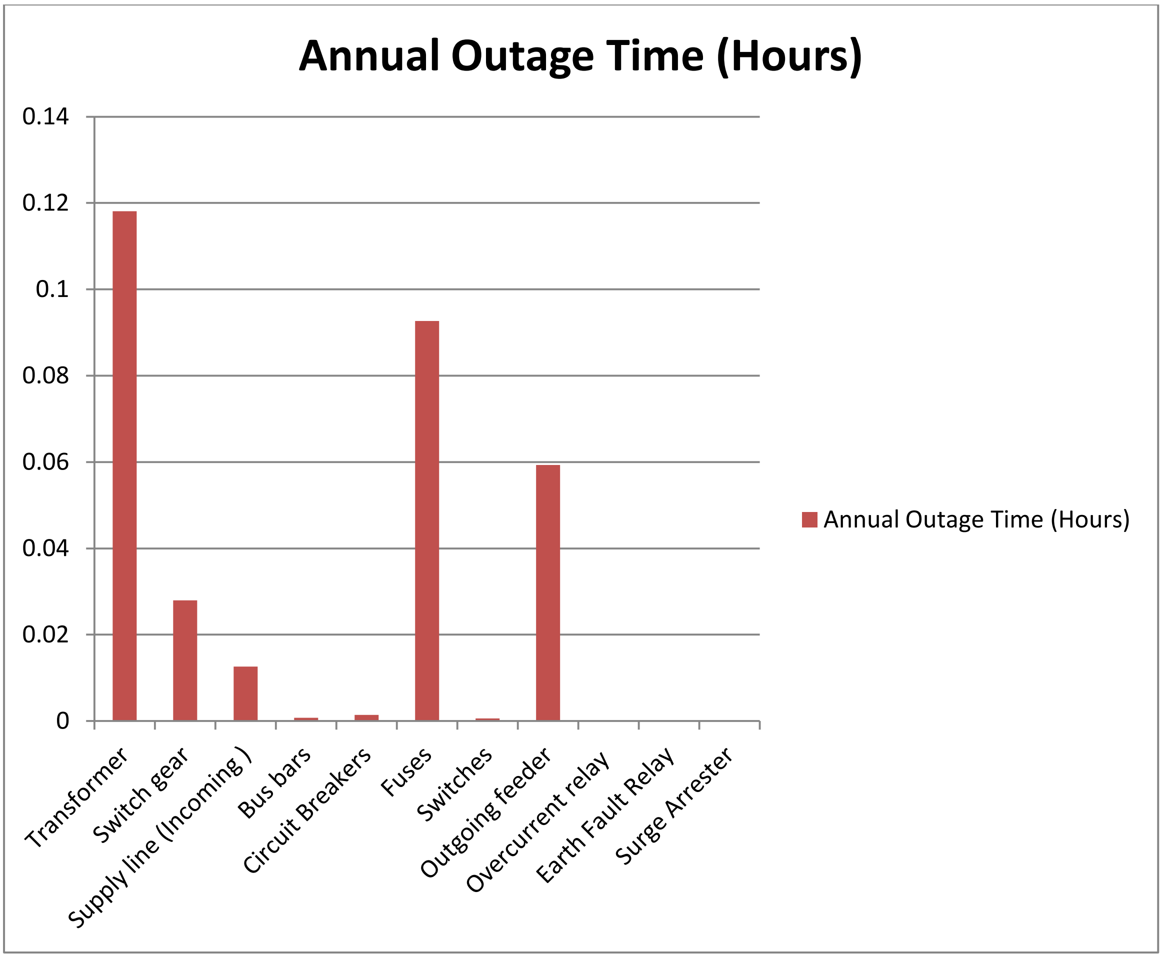

Figure 4.4: Bar Chart Showing the Annual Outage Time of Each Component

4.4.2 Interpretation of Component Reliability Evaluation Results

It is important to state here that the following assumptions were made in carrying out the reliability analysis of the distribution substation:

i. All interruptions recorded are statistically not dependent on each other
ii. Component failures are repaired before the next fault occurs.
iii. Generation and transmission are highly reliable and in operation to perform their intended function.
iv. Interruptions experienced by the customers are unplanned interruptions due to forced outage on the components.

From the above results, using table 4.12 which reflects the annual outage time / unavailability (U) of the components, the component contributing most to interruptions in the substation thereby affecting delivery of electricity to the customers is the transformer having a value of 0.1181, followed by the fuse 0.0927 and the outgoing feeder, 0.0593.

The transformer failure and or faults being a major contributor to the loss of supply to customers can be as a result of overloading of the transformer because of the number of customers' loads being served or internal faults due to mechanical faults or faults due to aging. In this case it can be easily seen that overloading appears to be a major reason why the transformer fails because the fuse, which is a self destructive device, is the second largest contributor to interruptions. And the operation of a fuse is to interrupt excess current which can be as a result of overload. Therefore in cases when higher rating of the fuse is used in order to prevent its quick rupturing as a result of overload, this brings about transformer failure due to overloading. Hence, it can be deduced that overloading amongst other things is a primary cause to transformer failure in the substation. The other reason for the transformer failure as explained earlier is insulation failure and ageing.

Also, among other factors that affect the outgoing feeder, the foremost is overloading which makes the lines to sag due to fault current which is higher than the normal current thereby increasing the probability of the lines coming in contact during a windy weather. Also, lines become anneal and eventually break as a result of reduced tensile strength brought about by higher currents flowing through the lines making them to exceed their thermal capacity.

The least component that fails is the surge arrester having no record of failure throughout the year. This implies that the substation is well protected against voltage surges that may arise as a result of lightning, fault or switching operation.

Earth fault relay and overcurrent relay has lower values of unavailability, 0.000049057 and 0.000018668 respectively. This implies that they contributed least to loss of supply and this may be due to the fact that these components are upstream on the feeder leg that feeds this substation and faults downstream of the transformer i.e. low voltage side, have been interrupted by protective device downstream. The relays and breakers are to protect the distribution feeder leg that is incoming to the distribution substation.

The bus bar and breaker also had low values of unavailability of 0.00077203 and 0.0014 respectively.

4.5 RELIABILITY INDICES EVALUATION OF THE SUBSTATION

Comparing Table 4.13 with Table 4.14 which gives the computed results for the overall availability of the substation to serve its customers, the availability of the substation was computed to have a value of 0.8967 and 0.8841 respectively. The value of the two results shown is highly compatible showing that availability of a system calculated through any of the two means is valid and can be accepted for interpretation of results. More so, the value shows that the substation is available for an approximate average of 88% to 90% in a year. The availability of the substation is low compared to the IEEE ASAI standard of 99.99989 for distribution substation availability. In addition, the substation has MTBF of 45.2784 and MTTR of 5.2139.

4.6 CUSTOMER RELIABILITY INDICES EVALUATION

The computed customer reliability indices using the formulae discussed in the previous chapter are shown in Table 4.14. The MATLAB code used in computing is shown in appendix D. The major assumption in computing the indices, in addition to the ones stated previously, is that interruptions affect all the customers at once. For instance, when there is single-phase fault on the transformer, it is expected that close to one-third of the customers will be affected but that is not the case. This is because most customers have the three single-phase supplies in their residences as a way of ensuring availability of power all the time whenever any of the phases is out. More so, there is no accurate data describing the number of customers on each phase of the transformer lines.

Table 4.13: Additional Basic Reliability Indices

Component	No. of Failures	Outage (hours)	Total (hours)	Failure rate (f/yr)	MTBF	MTTR	Availability
Transformer	27	458	8784	0.0031	325.3333	16.9630	0.9504
Switch gear	38	77	8784	0.0044	231.1579	2.0263	0.9913
Supply line (incoming)	19	70	8784	0.0022	462.3158	3.6842	0.9921
Bus bar	4	20	8784	0.00046322	2196	5.0000	0.9977
Circuit Breaker	6	25	8784	0.00068324	1464	4.1667	0.9972
Fuses	54	182	8784	0.0061	162.6667	3.3704	0.9797
Switches	4	16	8784	0.00045923	2196	4.0000	0.9982
Outgoing feeder	39	159	8784	0.0045	225.2308	4.0769	0.9822
Overcurrent Relay	2	2.5	8784	0.2083	4392	1.2500	0.9997
Earth Fault Relay	1	2	8784	0.1667	8784	2.0000	0.9998
Surge Arrester	0	0	8784	0	-	-	-
Total	194	1011.5	8784		45.2784	5.2139	0.8967

4.6.1 Interpretation of Customer Reliability Evaluation Results

The average outage duration, SAIDI, for each customer served is 3.8004 hours for the whole year. This is more than twice the IEEE standard 1366-2003 which gives a value of 1.5hours for North American Utility. This is a region that has sufficient power generation and robust system security. Therefore, according to the standard, the performance of this distribution substation system is low. The month of February had the highest SAIDI value followed by January with each having SAIDI value of 1.0000 and 0.9701 respectively. However, the month of December had the least value of SAIDI followed by June with each having SAIDI values of 0.0634 and 0.1045 respectively. This implies that the causes of interruptions were quickly identified and the faults cleared early enough in December and June.

This substation has a very acceptable low value of SAIFI for the year. This means that the frequency of interruptions spread across the year is actually low. Considering the SAIFI value alone, the system could have been mistaken to be very reliable which is not so. January and February have highest values of 0.1418 and 0.1194 respectively whilst December followed by June had lowest values of 0.0187 and 0.0299 respectively.

A CAIDI value of 5.25 implies that from the customer end, there was no supply of electricity for 5.25hours everyday for the whole year i.e. on the average, it takes 5.25 hours to restore power supply whenever there is interruption. In other words, any interruption lasts for an average of 5.25 hours throughout the year. The month of February had the highest monthly CAIDI followed by January with each having CAIDI value of 8.3750 and 6.8421 respectively which implies that in February it takes an average of 8.375 hours to restore power supply while for January it takes an average of 6.84 hours. The month of May had the lowest CAIDI followed by December with each having a CAIDI value of 3.1000 and 3.4000 respectively.

From the results in Table 4.14, the distribution substation has service or system reliability index, an ASAI value, of 88.41%. Utilities have been recorded to have a value of 99.99% or four nines, which means a SAIDI of 52 minutes per annum or 0.866 hour per year[1]. Hence with the value calculated for this substation, the reliability is very poor. The highest value recorded in the whole year was in December with a value of 0.9772 (97.72%) while the least value was recorded in the month of February with a value of 0.6149 (61.49%). The ASUI value gives the complement of ASAI by providing the value of the substation unavailability. The system has an ASUI of 0.1159.

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[1] This value is gotten when this formula is used i.e. ASAI = (8760-SAIDI)/8760

Table 4.14: Computed Customer Orientation Indices, January to December 2016 on Ayetoro 1 Substation

Month	Frequency of interruptions	Duration of interruption	Total Hours	No. of Customers	SAIDI (hrs/cust)	SAIFI (int/cust)	CAIDI (hrs/cust)	ASAI (p.u)	ASUI (p.u)
January	38	260	744	268	0.9701	0.1418	6.8421	0.6505	0.3495
February	32	268	696	268	1.0000	0.1194	8.3750	0.6149	0.3851
March	19	76	744	268	0.2836	0.0709	4.0000	0.8978	0.1022
April	22	96.5	720	268	0.3601	0.0821	4.3864	0.8660	0.1340
May	10	31	744	268	0.1157	0.0373	3.1000	0.9583	0.0417
June	8	28	720	268	0.1045	0.0299	3.5000	0.9611	0.0389
July	10	44	744	268	0.1642	0.0373	4.4000	0.9409	0.0591
August	13	48	744	268	0.1791	0.0485	3.6923	0.9355	0.0645
September	9	33	720	268	0.1231	0.0336	3.6667	0.9542	0.0458
October	15	70	744	268	0.2612	0.0560	4.6667	0.9059	0.0941
November	13	47	720	268	0.1754	0.0485	3.6154	0.9347	0.0653
December	5	17	744	268	0.0634	0.0187	3.4000	0.9772	0.0228
Total	194	1018.5	8784	268	3.8004	0.7239	5.2500	0.8841	0.1159

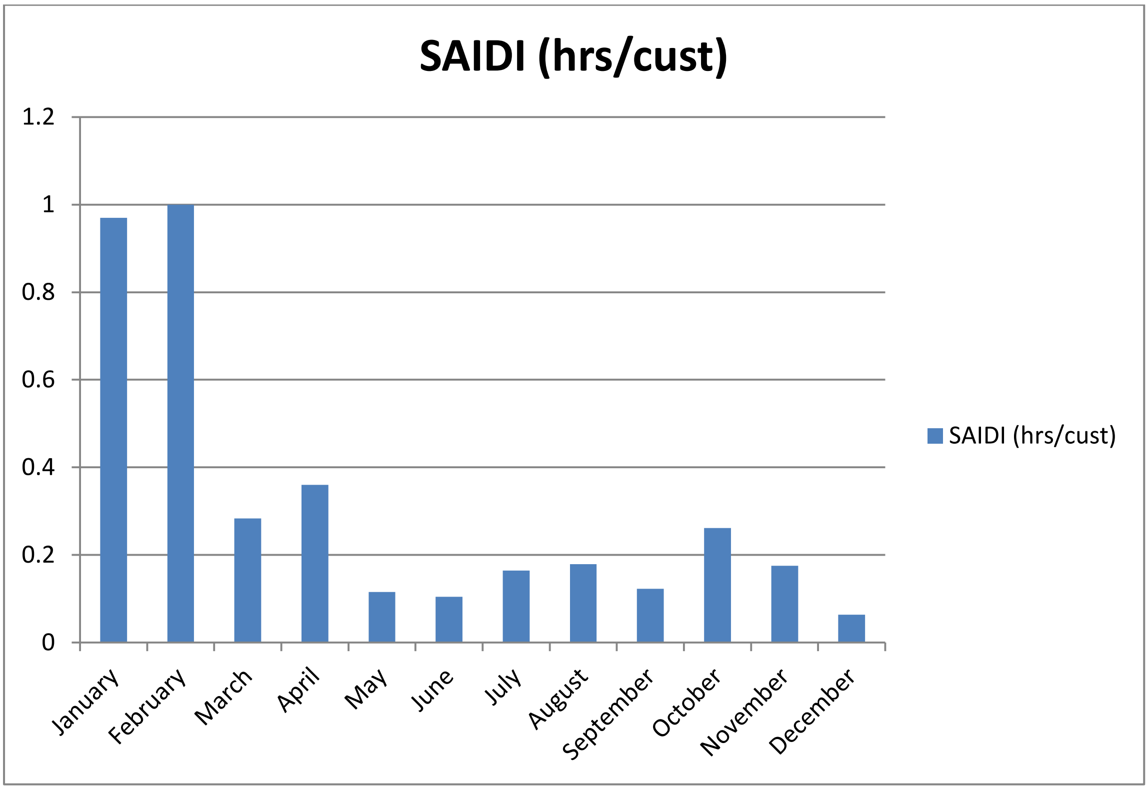

Figure 4.5: Bar Chart of SAIDI for Twelve Months

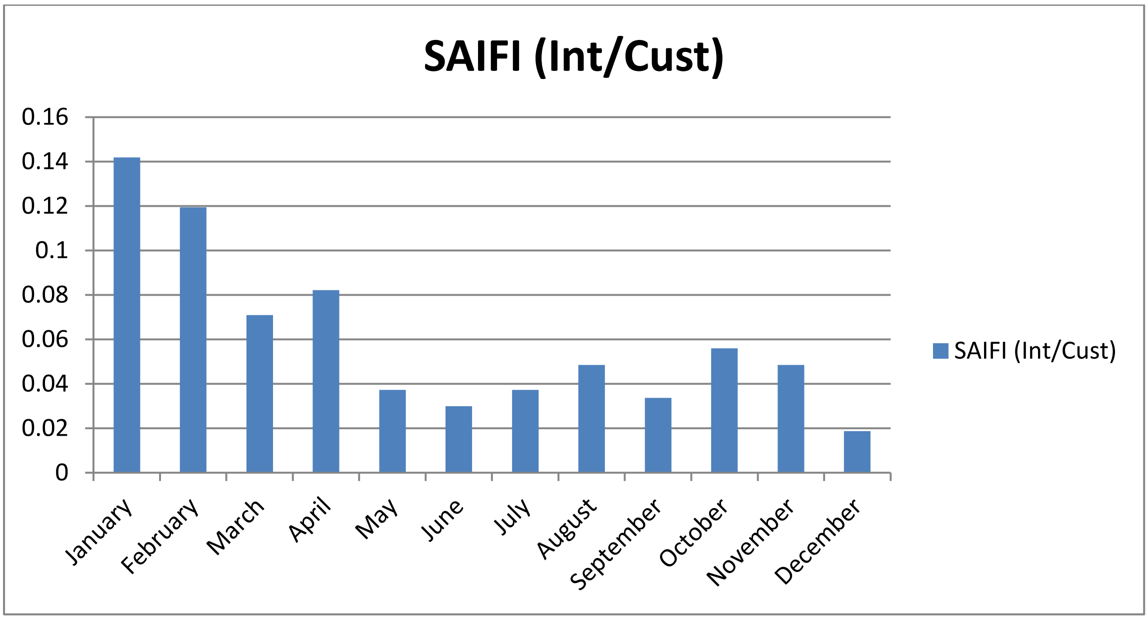

Figure 4.6: Bar Chart of SAIFI for Twelve Months

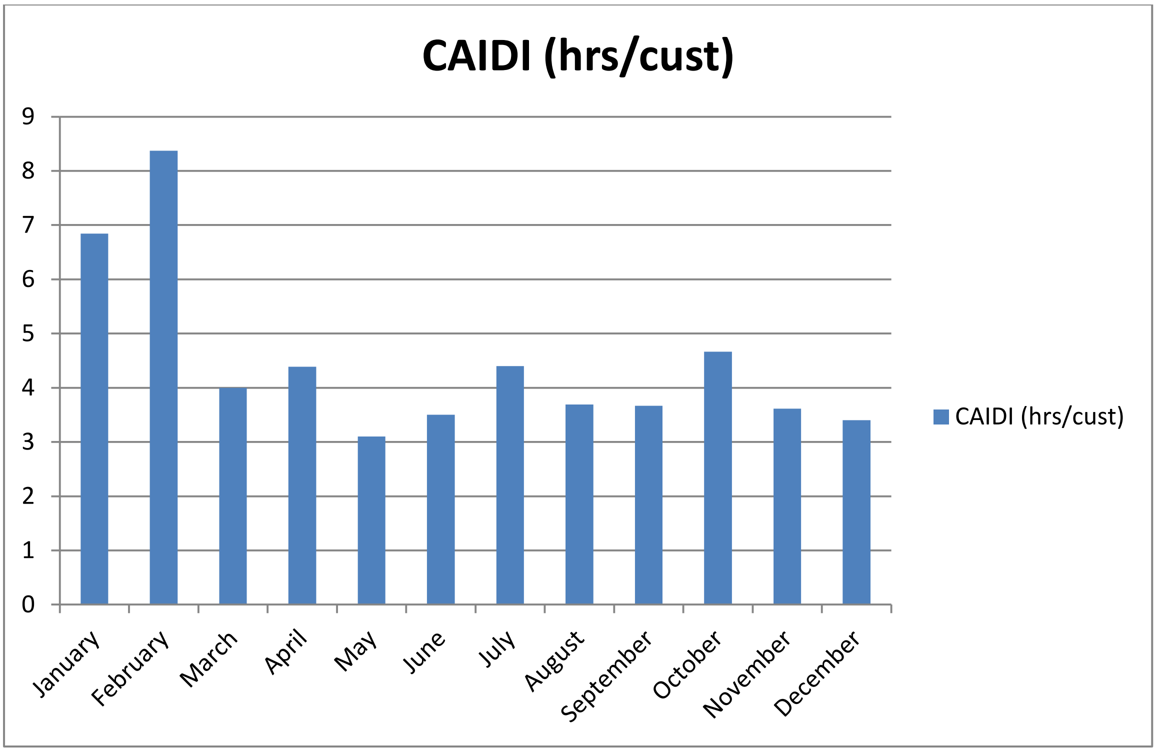

Figure 4.7: Bar Chart of CAIDI for Twelve Months

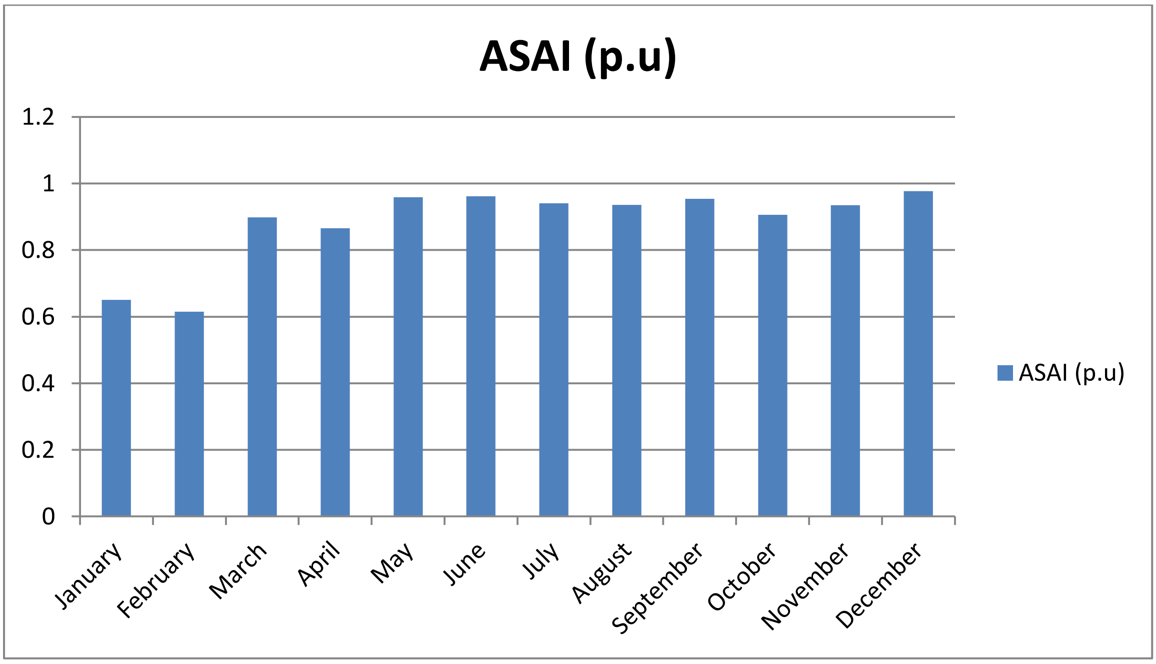

Figure 4.8: Bar Chart of ASAI for Twelve Months

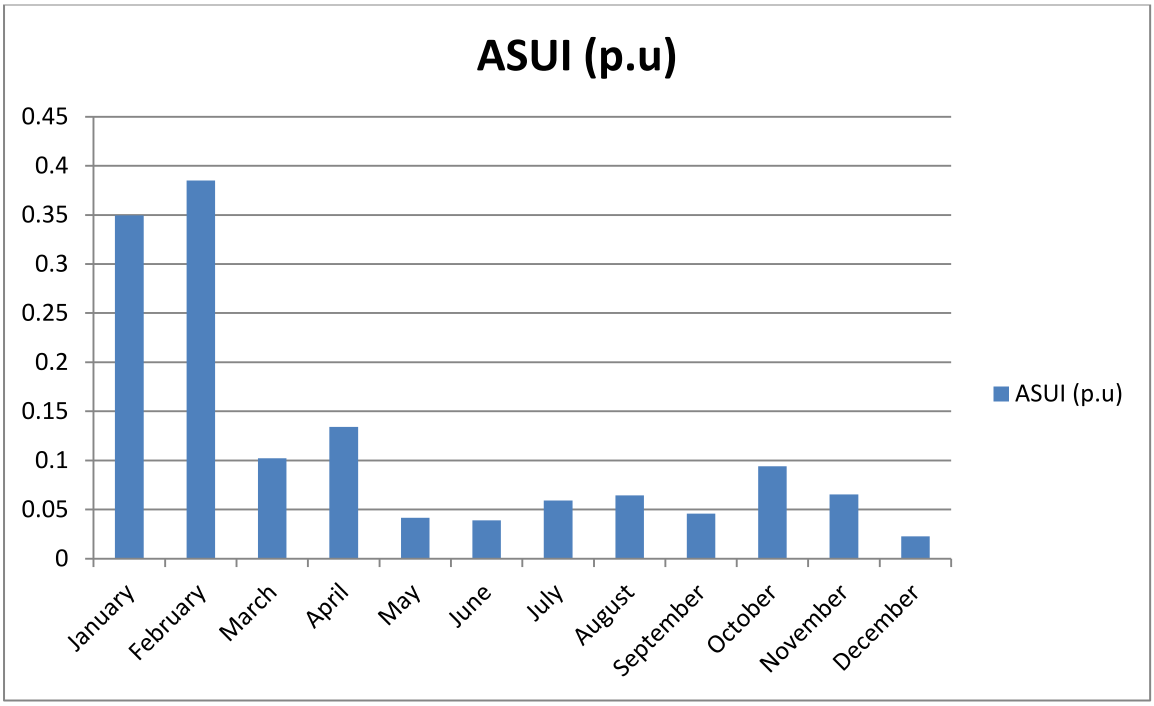

Figure 4.9: Bar Chart of ASUI for Twelve Months

4.6.2 Comparison of This Dissertation's Results with Reliability Benchmark Indices

The standard with which reliability of a distribution system is measured against is known as reliability benchmarks. The standards are given in order to provide a justification and give acceptable margin for the reliability performance of distribution networks. Based on IEEE Guide, the benchmarks for nine countries were computed for power distribution reliability as shown in Table 4.15.

From Table 4.15, Ayetoro 1 substation has a SAIDI of approximately 228 minutes per year, SAIFI of 0.7239, CAIDI of 315 minutes per outage and an ASAI of 88.41%. This substation has an incredibly low and acceptable value of SAIFI which means fewer interruptions and a high value of SAIDI which means longer duration of outages. The ASAI value also shows that the availability of the system is very low. Comparing this with the average reliability indices computed, it is obvious that the substation has worse performance and needs to be improved upon to increase its reliability indices. Figure 4.8 gives a graphical representation of the comparison.

However, it is important to note that the frequency of interruption, SAIFI is low which implies that the substation has a satisfactory value of SAIFI but needs to work on reducing the duration of the outages, SAIDI and CAIDI. The main challenge, therefore, is that the substation needs to intensify efforts in reducing the length or duration of outages in order to improve the availability and reliability of the substation. Therefore, it is not just component outages that affect the substation reliability but the duration it takes to restore the components back to service.

Table 4.15: Reliability Indices Benchmark (Rouse and Kelly 2011)

Country	SAIDI (Minutes/year)	SAIFI (Interruptions/Customer)	CAIDI (Minutes/Outage)	ASAI (%)
United States	240	1.5	123	99.91
UK	90	0.8	100	99.964
Italy	58	2.2	106	99.9991
Spain	104	2.2	114	99.968
Austria	72	0.9	112	99.97
Netherlands	33	0.3	75	99.97
Denmark	24	0.5	70	99.981
France	62	1	58	99.97
Ayetoro 1 (Nigeria)	**228**	**0.7239**	**315**	**88.41**

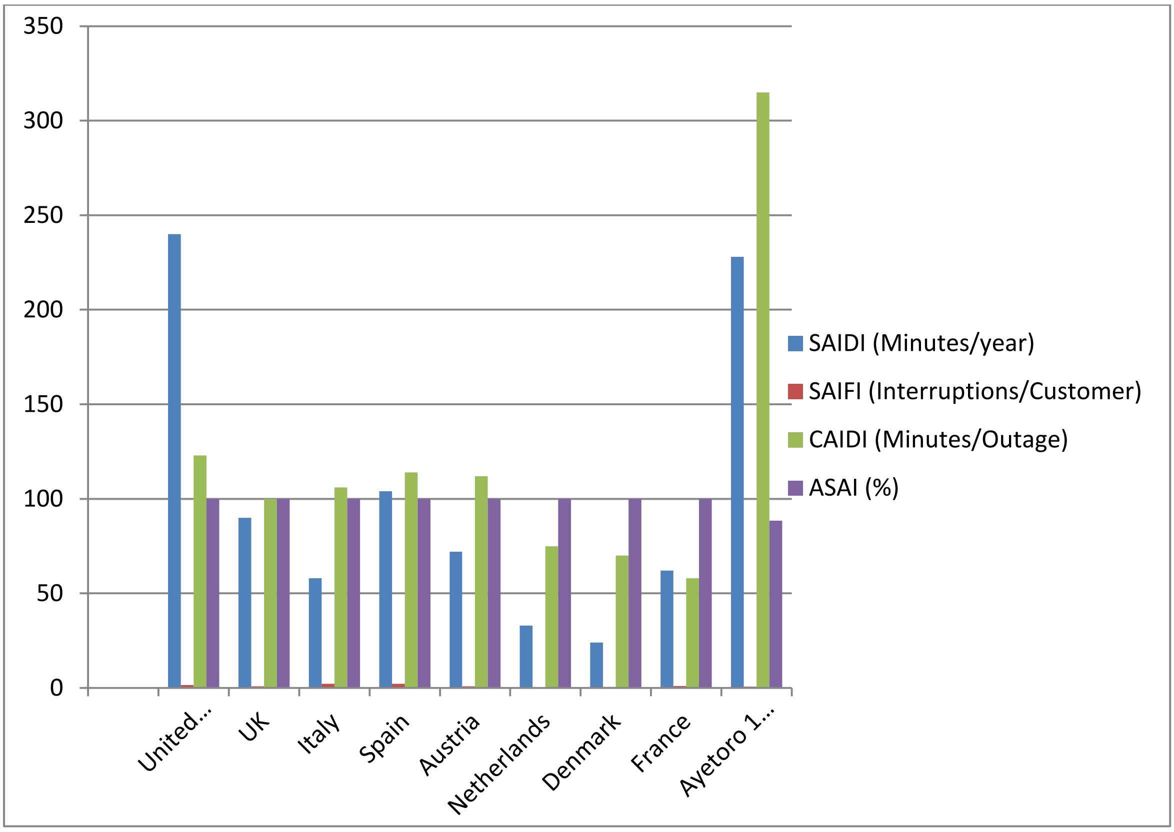

Figure 4.10: Bar Chart Showing Compared Reliability Indices

4.7 SUMMARY

This chapter presented the result obtained from the reliability evaluation carried out on the distribution substation components. The results were discussed and interpreted so as to identify the component contributing most to interruption of the system and also reflect the overall reliability of the substation and how this affects the consumers connected to the substation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 SUMMARY

In this dissertation, Ayetoro 1 substation, Aguda was chosen as a secondary distribution substation to study in order to evaluate the reliability of a typical substation in Nigeria. In order to achieve this, the substation was viewed to be in isolation from the rest of the power system. That is, the effect of insufficient generation was not considered and the impact of transmission subsystem failure which may arise as a result was also not considered. The analysis was carried out using 12 months' component outage frequency and its duration.

Network reduction method was employed in carrying out the reliability analysis of the substation. The substation has only one failure mode since it is designed as single-end fed radial network system. Hence, failure of a single component is sufficient enough to cause interruption of power supply. The component reliability of the substation was carried out and the result of the analysis showed that transformer contributed most to the cause of interruption to the customers.

From the analysis carried out so far, it has been demonstrated that though the frequency of outage affects reliability but the outage duration has more impact on the system availability. The month of January had the highest number of failures and February had the highest duration of outages. However, it was the month of February that had higher value for system unavailability throughout the year. This implies that, even if there are failures and faults in a component in the system, it is the duration for which the outage is allowed that greatly impacts the overall system.

Furthermore, the month of December had the highest ASAI value which, though is far below the recent expected value of 0.99989 according to IEEE ASAI standard, shows that the utility company puts concerted effort to ensure that customers enjoy less interruptions in the festive and holiday seasons. This has the advantage of generating more revenue from energy used as the population of electricity users tends to increase at that period. One of the reasons for this high value is that, there were fewer sustained interruptions which imply that component outages were quickly attended to and that the components must have maintained earlier to prevent unplanned interruptions.

5.1 ACHIEVEMENTS

This dissertation, by using Ayetoro 1 substation as case study for carrying out reliability evaluation of a secondary distribution system in Nigeria, has been able to identify transformer as the component contributing most to consumer reliability problems followed by the fuse and the outgoing feeder.

Also the overall reliability of the distribution system showed that the substation performance is poor with respect to the standard benchmark. Furthermore, the work shows that consumer reliability is really hampered by the duration of the outages more than the frequency of outages. This is also obvious from the result obtained as component outage duration takes time hence there are fewer interruptions i.e. since the components are out of service there is no way it can fail again.

5.2 RECOMMENDATIONS

Based on the work done in this dissertation, the following recommendations are made:

a. The utility company should continue to keep accurate record of interruptions, the causes and durations as these will really help to carry out concise research work.
b. Also, efforts should be put in place to see that when there is a component outage, the duration is reduced greatly in order to achieve a more reliable system. And this can be done by ensuring that the customers have a means of reporting outages to the utility company and speedy response whenever outages are reported. This might mean having more hands on deck, i.e. more manpower to sufficiently cover the different areas. Digital monitoring of the substation and lines as it is done for transmission lines and substations is suggested. This may be expensive to implement because there are more secondary distribution substations scattered around a primary distribution network but the benefits cannot be overemphasized. And this can be determined by looking into the reliability cost of the substations if such is to be implemented.
c. There should be conscious effort to ensure that duration of outages is reduced to the lowest minimum as possible as this will help improve the reliability of the substation. Reliability is important, but not to be achieved through crooked means

like, hastily pushing repairs which may encourage short cuts by the utility workers. Moreover, there is higher probability of making mistakes when the workers are over worked and tired. Hence, it is very important that the utility workers are capable, having the right set of tools, take enough breaks, and follow normal safety precautions for instance working under active lightning should be avoided.

d. The customers should be enlightened to see the substation as their property as this will foster quick reportage of failures. This will also aid in protection of the substation from vandals.
e. There have been reported cases of customers tampering with the substation components. An example is employing the services of a technician to fix fuse related problems. And in many cases, it has proved to be dangerous as the fuse ratings used are higher in a bid to ensure that there is no loss of supply but this affects the transformers in many cases as through faults.
f. The design of the substation can be improved to be a double-end fed radial system to ensure better supply of electricity which automatically improves the reliability of the substation.
g. Overloading seems to be a major problem for most distribution substations; hence utility company should have accurate data of their customers. And for newer substations, there must be a major consideration and effective design for more customers as the substation continues to exist. Also, building more customer distribution substations will help reduce the overloading of the transformer.
h. Proper and regular inspection of utility facilities like poles will also improve reliability of the substation.

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APPENDIX A

Reliability Data Of Distribution Substation For Twelve Months (2016)

Ayetoro 1 Substation, Aguda, Lagos State.

Components	January		February		March	
	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)
Transformer	10	186	8	207	4	38
Switchgear	13	24	12	18	7	9
Supply line	3	10	1	4	Nil	Nil
Busbars	Nil	Nil	1	6	Nil	Nil
Circuit breakers	Nil	Nil	Nil	Nil	Nil	Nil
Fuses	9	14	2	12	5	17
Switches	Nil	Nil	Nil	Nil	1	3
Outgoing feeder	3	26	7	19	2	9
Overcurrent Relay	Nil	Nil	1	2	Nil	Nil
Earth Fault Relay	Nil	Nil	Nil	Nil	Nil	Nil
Surge Arrester	Nil	Nil	Nil	Nil	Nil	Nil

Components	April		May		June	
	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)
Transformer	Nil	Nil	1	8	Nil	Nil
Switchgear	4	18	Nil	Nil	Nil	Nil
Supply line	5	17	Nil	Nil	Nil	Nil
Busbars	Nil	Nil	Nil	Nil	Nil	Nil
Circuit breakers	2	13	Nil	Nil	1	6
Fuses	7	32	3	12	5	14
Switches	Nil	Nil	Nil	Nil	Nil	Nil
Outgoing feeder	3	16	6	11	2	8
Overcurrent Relay	1	0.5	Nil	Nil	Nil	Nil
Earth Fault Relay	Nil	Nil	Nil	Nil	Nil	Nil
Surge Arrester	Nil	Nil	Nil	Nil	Nil	Nil

Components	July		August		September	
	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)
Transformer	Nil	Nil	2	14	1	6
Switchgear	Nil	Nil	Nil	Nil	Nil	Nil
Supply line	3	10	Nil	Nil	1	5
Busbars	Nil	Nil	1	8	2	6
Circuit breakers	Nil	Nil	Nil	Nil	Nil	Nil
Fuses	5	18	9	23	Nil	Nil
Switches	Nil	Nil	Nil	Nil	1	6
Outgoing feeder	2	16	1	3	4	10
Overcurrent Relay	Nil	Nil	Nil	Nil	Nil	Nil
Earth Fault Relay	Nil	Nil	Nil	Nil	Nil	Nil
Surge voltage Protection	Nil	Nil	Nil	Nil	Nil	Nil

Components	October		November		December	
	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)	No. of failures	Outage Time (Hours)
Transformer	Nil	Nil	1	6	Nil	Nil
Switchgear	Nil	Nil	2	8	Nil	Nil
Supply line	4	15	2	9	Nil	Nil
Busbars	Nil	Nil	Nil	Nil	Nil	Nil
Circuit breakers	1	3	Nil	Nil	2	3
Fuses	8	35	1	5	Nil	Nil
Switches	Nil	Nil	2	7	Nil	Nil
Outgoing feeder	1	15	5	12	3	14
Overcurrent Relay	Nil	Nil	Nil	Nil	Nil	Nil
Earth Fault Relay	1	2	Nil	Nil	Nil	Nil
Surge Arrester	Nil	Nil	Nil	Nil	Nil	Nil

APPENDIX B

```
% This code computes the failure rate for each month for the
components
% The total hours in each month of a calendar year starting
from January is represented by m
% The calculated failure rate is given by g
% The failure rate per year is calculated as mean of g and
represented by t
% The average outage time is calculated as mean of y and
represented by d
% The annual outage time is represented by r


m = [744,696,744,720,744,720,744,744,720,744,720,744];
x = input('enter the values of monthly component no of
failures for the year: ')
g = x./m
t = mean(g)
y = input('enter the values of the monthly outage time for
the component: ')
d = mean(y)
r = t*d
```

APPENDIX C

```
%   This is also to further calculate the component
reliability indices
%   The total hours in the calendar year is represented by w
%   MTBF means Mean Time Between Failure
%   MTTR means Mean Time To Repair
w = 8784;
a = input('Enter the number of failures: ')
MTBF = w/a
c = input('Enter the total duration of outages: ')
MTTR = c/a
Availability = MTBF/(MTBF+MTTR)
```

APPENDIX D

```
%   This programme computes the customer based reliability
indices
%   SAIDI is represented as z
%   SAIFI is represented as x
%   CAIDI is represented as c
%   ASAI is represented as V
%   ASUI is represented as b
%   the total number of customers supplied is represented as
s
s = 268;
a = input('enter the total outage duration for the month: ')
z = a/s
d = input('enter the frequency of outages for the month: ')
x = d/s
c = z/x
f = input('enter the total hours in the month: ')
v = 1-(a/f)
b = a/f
```